LESSONS LEARNED FROM THE TEXAS BLACKOUTS: RESEARCH NEEDS FOR A SECURE AND RESILIENT GRID

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

C O N T E N T S

March 18, 2021

LESSONS LEARNED FROM THE TEXAS BLACKOUTS: RESEARCH NEEDS FOR A SECURE AND RESILIENT GRID

THURSDAY, MARCH 18, 2021

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Committee met, pursuant to notice, at 10 o'clock a.m., via Webex, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

Lessons Learned from the Texas Blackouts: Research Needs for a Secure and Resilient Grid
Thursday, March 18, 2021
10:00 AM EDT
Cisco Webex

PURPOSE

The purpose of the hearing is to understand what caused the recent extended power outages in Texas and other southern and midwestern states during a severe winter storm over the second weekend of February, and to examine associated grid research and development needs. Witnesses and Members will discuss grid security research activities at the Department of Energy, including relevant grid technology, energy generation technology, and cybersecurity research. The hearing will also serve as a legislative hearing for a bill that was introduced in the 116th Congress and is expected to be reintroduced in this Congress by Rep. Ami Bera, the *Grid Security Research and Development Act* (H.R. 5760 in the 116th Congress). This bill would authorize an interagency research, development, and demonstration program on electric grid and energy system cybersecurity, physical security, resilience, and emergency response.

WITNESSES

- **Dr. Jesse Jenkins,** Assistant Professor of Mechanical and Aerospace Engineering, Andlinger Center for Energy and the Environment at Princeton University
- **Dr. Varun Rai,** Associate Dean for Research; Professor of Public Affairs, LBJ School of Public Affairs at the University of Texas at Austin
- **Mr. Juan Torres,** Associate Laboratory Director, Energy Systems Integration National Renewable Energy Laboratory
- **Ms. Beth Garza,** Senior Fellow, R Street Institute
- **Dr. Sue Tierney,** Senior Advisor, Analysis Group

BACKGROUND

Sequence of Events

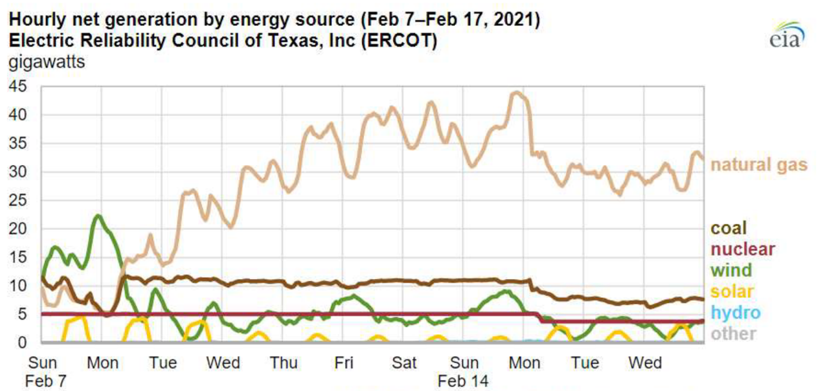
In 2020, natural gas, wind, coal, nuclear, and solar energy provided 46%, 23%, 18%, 11%, and 2% of Texas's electricity, respectively.[1]

Late Sunday, February 14th, Winter Storm Uri descended on Texas and the surrounding region, leading to unprecedented low temperatures. Early in the morning on Monday, February 15th, heat and electricity demand surged. At the same time, roughly 30 gigawatts of Texas's 107,514 gigawatts installed generation capacity tripped offline due to freezing components and freezing

[1] https://www.statista.com/chart/24202/texas-energy-mix-by-fuel-type/

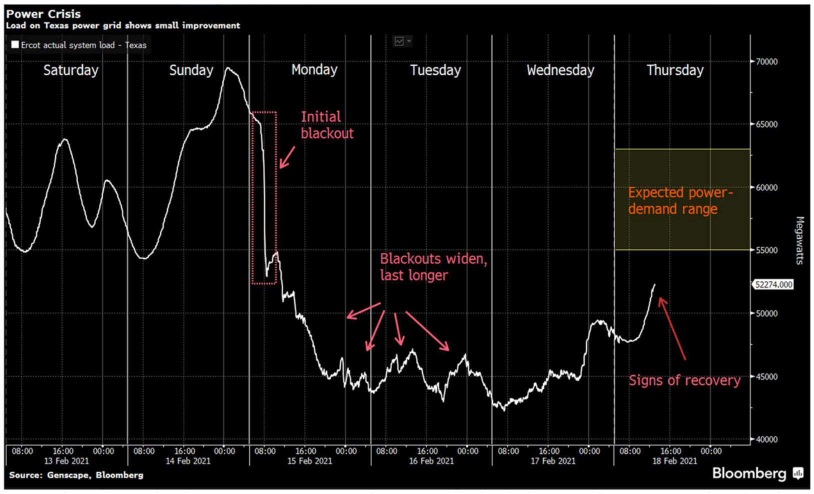
fuel supplies. Natural gas, coal, nuclear, wind, and solar plants were all affected. Natural gas outages had the biggest impact, because the state generates almost half of its electricity using natural gas. The impact from the loss of natural gas is two-fold, since gas is also used to heat homes directly as a heating fuel. These power plants primarily faulted because they were not designed to operate in such severe cold weather conditions. During this time, the peak electricity demand and power plant outages were both at all time highs, greater than any scenario ever planned for.

By the evening of February 15, two million Texas households had no electricity. More generation resources failed as the freeze persisted and at the peak of the crisis, 48.6% of the generation assets under the Electric Reliability Council of Texas (ERCOT), Texas's grid operator, were offline. By February 16, over 4 million households had no electricity.[2] On Thursday the 18th, ERCOT grid load began to climb substantially and exceeded 50 gigawatts for the first time in over three days. However, the sustained power outages had spawned a secondary crisis as bursting water pipes, households dripping their pipes to avoid bursts, and lack of electricity for water management resulted in mass water outages across the state. As of February 25, over one million Texans were still without safe drinking water access.



Source: U.S. Energy Information Administration, Hourly Electric Grid Monitor (ERCOT net generation by energy source)

[2] http://www.ercot.com/content/wcm/key_documents_lists/225373/Urgent_Board_of_Directors_Meeting_2-24-2021.pdf



Texas Electricity Load, February 13-18. Times are in GMT, six hours ahead of Houston. Source: Javier Blas, Bloomberg

The Texas grid was also at risk of a longer-term catastrophic failure. Power plants are designed to operate within a certain frequency range, and their equipment will be damaged or destroyed if they operate outside of those ranges for more than a brief period of time. The ratio of electricity demand to supply needs to remain fairly matched to maintain the frequency of the grid. In a preliminary report on February 24, ERCOT acknowledged that due to the mismatch in supply and demand, the Texas grid was operating below 59.4 Hz for 4 minutes and 23 seconds in the wee hours of February 15. Had grid managers not forced more controlled outages and operations continued below 60 Hz for even five more minutes, more generation units would have tripped offline automatically, creating a cascading failure that would have resulted in "total collapse" of the Texas power grid and no electricity in Texas for several weeks.[3]

Although the generation failures were the largest factor by far in the Texas blackouts, transmission, distribution, and overall network failures (such as downed power lines and overloaded transformers) also contributed.

Fallout

More than seventy Texans lost their lives as a result of Winter Storm Uri. More than a dozen of those seventy were inside homes that lost their heat with the utility outages.

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[3] http://www.ercot.com/content/wcm/key_documents_lists/225373/Urgent_Board_of_Directors_Meeting_2-24-2021.pdf

A Texas-based economic research firm projected that Winter Storm Uri could cost $195 billion-$295 billion in damages and economic harm, making it potentially more financially impactful than Hurricane Harvey.[4]

On February 23, five of ERCOT's sixteen-member board announced they would resign, and a sixth withdrew his application to the board.[5] On February 26, ERCOT barred Griddy, an electricity retailer that served 29,000 customers in Texas, from participating in the state's public power market because its billing plans had resulted in residential customers being billed $5,000 or more for five days of service.[6] On March 1, the Chairman of the Texas Public Utility Commission (PUC), DeAnn Walker, submitted her resignation to the Governor of Texas.[7] That same day, the oldest electric power cooperative in Texas, Brazos Electric Power Cooperative, filed for bankruptcy. Brazos and its subsidiaries serve 1.5 million consumers in Texas.[8]

On March 3, ERCOT removed its CEO Bill Magness, offering an $800,000 severance which Magness did not accept. On March 4, ERCOT's independent market monitor, Potomac Economics, determined that ERCOT had overcharged Texas consumers by $16 billion by keeping prices at the wholesale market cap of $9,000/MWh for 32 hours longer than necessary. The ERCOT wholesale market incurred $55 billion in charges over just a week. Potomac Economics recommended that the Texas PUC should retroactively reduce the price of power for the week of February 14-19 and eliminate some of the $16 billion overcharges, but the PUC declined to take that action.[9] On March 8, 2021, a second PUC commissioner, Shelly Botkin, resigned.[10] On March 9, Just Energy group, an electricity retailer headquartered in Canada with major operations in Texas, filed for bankruptcy in the U.S.[11]

Research, Development, Demonstration, and Commercial Application Solutions

Extreme weather events such as Winter Storm Uri and other risks such as cybersecurity events are now significant and growing threats to the security of our nation's electric grid. Additionally, we are constantly transforming our grid to adapt to a rapidly changing electricity generation mix in efforts to meet climate goals and lower costs for consumers. The Department of Energy plays an important role in improving our electric grid and hardening it against these physical and cyber security events, as well as against the effects of climate change.

Department of Energy, Office of Electricity (OE)

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[4] perryman-preliminary-estimates-of-economic-costs-of-the-february-2021-texas-winter-storm-02-25-21.pdf (perrymangroup.com)
[5] https://www.texastribune.org/2021/02/23/ercot-members-resign-texas/
[6] https://www.bloomberg.com/news/articles/2021-02-27/griddy-barred-from-texas-power-market-for-payment-breach?sref=veMZyIzD
[7] EvbcLO4XUAIB4Ki (640×841) (twimg.com)
[8] https://www.reuters.com/article/idUSKCN2AT1FE?il=0&utm_source=reddit.com
[9] https://www.texastribune.org/2021/03/05/texas-ercot-electric-bills/
[10] https://www.houstonchronicle.com/business/energy/article/PUC-Commissioner-Shelly-Botkin-resigns-winter-stor-16010194.php
[11] https://www.eenews.net/energywire/2021/03/10/stories/1063727033?utm_campaign=edition&utm_medium=email&utm_source=eenews%3Aenergywire

The DOE Office of Electricity's main mission is to support grid modernization and resilience through programs that improve the planning and operational capabilities of the electrical sector at both the transmission and distribution level. This includes research on a variety of technologies related to the smart grid, demand response, microgrids, energy storage, renewable energy integration, transformer resilience, grid planning, sensor development, and power flow controllers. OE also provides technical assistance to States, regional entities, and tribes on a variety of topics to assist with the development and implementation of their electricity-related policies and handles permitting of cross-border transmission lines and coordinating Federal transmission permitting on Federal lands. OE was funded at $211.7 million in Fiscal Year 2021.

Department of Energy, Office of Cybersecurity, Energy Security, and Emergency Response (CESER)

The DOE's Office of Cybersecurity, Energy Security, and Emergency Response (CESER) was created in early 2018. Prior to 2018, the Department of Energy research programs on grid modernization and grid security were housed under a single office called the Office of Electricity and Energy Reliability. The mission of CESER is to lead "the Department of Energy's emergency preparedness and coordinated response to disruptions to the energy sector, including physical and cyber-attacks, natural disasters, and man-made events".[12] CESER programs support improving cybersecurity preparedness in the energy sector; coordinating responses and recovery from cyber incidents; detecting and mitigating cyber risks for energy sector owners and operators; and sharing of threat information among energy sector partners, in addition to a variety of other activities. CESER partners with other federal agencies, including DHS, DOD, and NIST, and industry partners in carrying out its mission. CESER received $156 million in funding for FY21.

LEGISLATION

Draft Grid Security Research and Development Act

In the 116th Congress, Congressman Bera and Energy Subcommittee Ranking Member Weber introduced the *Grid Security Research and Development Act* (H.R. 5760). This bill would authorize a cross-agency research, development, and demonstration program to advance electric grid and energy system cybersecurity, physical security, resilience, and emergency response. The bill included a focus on concurrent and co-located disasters and a technical assistance program to help communities develop plans for preventing and recovering from various power outage scenarios. It also included authorization of test bed facilities to test and improve cybersecurity devices, components, and processes; interagency coordination to advance security capabilities for the electricity sector; authorization of an education and workforce training program led by DOE to identify core skills used by electric grid security professionals and to develop methods to retrain electricity sector personnel; and authorization of a research program to ensure the resilience and security of critical integrated grid infrastructure. The bill passed the House on suspension by voice vote, and as part of the *Clean Economy Jobs and Innovation Act* (H.R. 4447), but was not enacted.

[12] https://www.energy.gov/ceser/ceser-mission

Chairwoman JOHNSON. And without objection, the Chair is authorized to declare recess at any time.

Before I deliver my opening remarks, I want to note that Committee is meeting virtually, and I want to announce a couple of reminders to the Members about the conduct of the hearing. First, Members should keep their video feed on as long as they are present in the meeting. Members are responsible for their own microphones. Please also keep your microphones muted unless you are speaking. And finally, if Members have documents they wish to submit for the record, please email them to the Committee Clerk, whose email address was circulated prior to the meeting. These are our standard instructions, and I know we'll all cooperate.

Just a month ago on Valentine's Day, Winter Storm Uri descended upon Texas and broke cold temperature records across the State. Forty-eight percent of the electricity generation capacity for the State grid went offline due to frozen components and frozen fuel supplies. By February the 16th, four million Texas households were without power. Millions of Texans had no heat and no electricity for three days or more with temperatures well below freezing. At least 70 people died as a result of Winter Storm Uri and these power outages. One of them was just 11 years old. Cristian Pineda died of hypothermia after electricity was cutoff in his family's mobile home in Conroe, Texas. He had been trying to stay warm under a pile of blankets with his three-year-old brother. An eight-year-old girl and her mother died of carbon monoxide poisoning in Harris County after they ran the family car to try to stay warm.

The electricity and heating crisis led to a severe water crisis. Water pipes burst, flooding homes. By Friday the 19th, 12 million Texans were under a boil water advisory because the water supplies had fallen too low. And all of this happened in the midst of the greatest public health crisis this country has seen in a century, when families are dealing with lost loved ones, lost jobs, illness, and isolation.

I'm lucky enough to have lost power for just 1 day, and I kept warm overnight just by piling on blankets.

Texans, Texans deserve better. There was a lot of discussion in the immediate aftermath of the Texas blackouts about who to blame. There was a lot of misinformation and political jockeying. What seems clear already is that Electric Reliability Council of Texas, better known as ERCOT, failed to prepare its energy infrastructure for extreme weather conditions. It is unacceptable that millions of Texans were left without power for days on end during one of the worst winter storms in our State's history.

But I know there is more for us to examine about what happened in Texas, and it is our responsibility as policymakers to get answers. Why didn't the models used by the utilities see this coming? Which systems and components performed well and which failed? Could better demand response technologies have allowed the Texas grid operators to ease the burden of these charges and outages? What was the role of climate change in enabling the conditions for this extreme weather episode? How ready is the electricity sector for future extreme weather events like wildfires and heat waves? That's what I had thought we'd be looking forward to but not this type of winter. Will Texas be brought to its knees if our grid is attacked by a sophisticated adversary?

If we can get a clear-eyed understanding of how these failures occurred, we can help prevent them from happening in the future. What Texans endured last month must not be in vain. We must learn from this episode and redouble our research efforts in support of a more reliable, resilient electricity sector.

Last Congress, our fellow Committee Member, Mr. Bera of California, introduced a bipartisan bill with Mr. Weber of Texas to do just that called the *Grid Security Research and Development Act*. I understand he intends to reintroduce this bill this Congress, and I look forward to working with him and my other colleagues on both sides of the aisle for this important effort.

Today, I look forward to the testimony of our witnesses, some of whom were also personally affected by power outages. These five panelists represent some of the foremost experts in electricity reliability in the country, and we are honored to have them with us today. I hope that as the Texas Legislature considers what to do in response to this crisis, they will heed the lessons that we all share with us today.

[The prepared statement of Chairwoman Johnson follows:]

Just one month ago on Valentine's Day, Winter Storm Uri descended on Texas and broke cold temperature records across the state. Forty-eight percent of the electricity generation capacity for the Texas grid went offline due to frozen components and frozen fuel supplies. By February 16, four million Texas households were without power. Millions of Texans had no heat and no electricity for three days or more with temperatures well below freezing.

At least 70 people died as a result of Winter Storm Uri and these power outages. One of them was just eleven years old. Cristian Peneda died of hypothermia after electricity was cut off in his family's mobile home in Conroe. He had been trying to stay warm under a pile of blankets with his three-year-old brother. An eight-year-old girl and her mother died of carbon monoxide poisoning in Harris County after they ran the family car to try to stay warm.

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Texans deserve better.

There was a lot of discussion in the immediate aftermath of the Texas blackouts about who to blame. There was a lot of misinformation and political jockeying, too. What seems clear already is that the Electric Reliability Council of Texas, better known as ERCOT, failed to prepare its energy infrastructure for extreme weather conditions. It is unacceptable that millions of Texans were left without power for days on end during one of the worst winter storms in our state's history.

But I know there is more for us to examine about what happened in Texas, and it is our responsibility as policymakers to get answers. Why didn't the models used by the utilities see this coming? Which systems and components performed well and which failed? Could better demand response technologies have allowed the Texas grid operators to ease the burden of these outages? What was the role of climate change in enabling the conditions for this extreme weather episode? How ready is the electricity sector for future extreme weather events, like wildfires and heat waves? Will Texas be brought to its knees if our grid is attacked by a sophisticated adversary?

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I yield to Ranking Member Lucas.

Chairwoman JOHNSON. I now recognize and yield to our Ranking Member, Mr. Lucas.

Mr. LUCAS. Thank you, Chairwoman Johnson, for holding this important and timely hearing.

Today, we have an opportunity to examine last month's blackouts in Texas and other Southern and Midwestern States. There is no better time to hear about the ongoing efforts by industry, Federal agencies, and the Department of Energy (DOE) national labs to learn from these events and adapt for the future.

Before we begin, I'd like to express my gratitude for the safety of my Texas friends here, and I hope your families are well, and your districts, like mine, are on their way to recovery.

I'd also like to commend the public utilities and member-owned cooperatives in my State for how well they managed their crisis and ensure the safety of their customers and my constituents.

Physical and cyber threats to our power grid are constantly evolving. This incident, alongside last year's wildfires on the West Coast and the recent solar winds cyber attack highlights the need for congressional action to ensure the security and resilience of the U.S. energy sector.

As we discussed these events and their causes, we on the Science Committee have a responsibility to focus on the long-term technological solutions that can help us prepare for and respond to the next trial. As the past year has shown, it's not a matter of if our grid will be tested again, it's a matter of when. The Science Committee has jurisdiction over DOE's electricity delivery, cybersecurity, energy security, and emergency response research and development (R&D) activities. This work is essential to maintaining the stability and flexibility of our grid not just for today's needs but also for the next generation's.

Through its world-leading national laboratories and Grid Modernization Laboratory Consortium, DOE supports R&D in advanced grid modeling, grid energy storage, information sharing, and advanced control systems. By partnering with industry DOE can provide stakeholders with critical expertise and enable the deployment of new grid security tools and technologies.

This morning, we will hear from Beth Garza, a Senior Fellow at R Street's Energy and Environmental Policy Team. She served as the Director of the Electric Reliability Council (ERCOT) of Texas, known to all of us as ERCOT, Independent Marketing Monitor from 2014 through 2019. Beth brings a critical perspective to this distinguished witness panel and could provide first-hand insight into ERCOT and the power supply industry as a whole. I look forward to her testimony highlighting the needs and challenges of our diverse and complex power delivery system.

This hearing also will serve as an opportunity to discuss grid security legislation. Last year, H.R. 5760, the *Grid Security Research* *and Development Act*, passed by the House with strong bipartisan support. This legislation authorized the DOE (Department of Energy) research, development, and demonstration (RD&D) activities that focus on the discovery of innovative tools and technologies for energy sector security and resilience. The provisions of this bill were originally a central component of the bipartisan and bicameral *Energy Act of 2020*, which became law last Congress.

Unfortunately, due to last-minute jurisdictional claims from outside Committees, this bill had to be removed from the *Energy Act* at the 11th hour. I am hopeful that we can work together to once again introduce and pass grid security legislation this session, preferably this year.

The energy sector faces unique challenges that require institutional knowledge and data that only the Department of Energy can provide. DOE is responsible for energy-critical infrastructure, which includes electric power, oil, and natural gas. It also has authority over the cybersecurity of energy delivery systems. Providing DOE researchers and industry with the tools they need to ensure the long-term security and resilience of our electric grid should be something we can all agree on.

This Congress, I will prioritize getting these provisions over the finish line, working with my friends on both sides of the aisle to get this done. I thank our witnesses today for their valuable testimony at such a critical time, and I look forward to a productive discussion about how Federal agencies can work with industry to deliver affordable power to American homes, businesses, and essential services.

Thank you, Madam Chair, and I yield back the balance of my time.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Johnson for holding this important and timely hearing. Today, we have an opportunity to examine last month's blackouts in Texas and other southern and midwestern states. There is no better time to hear about the ongoing efforts by industry, federal agencies, and the Department of Energy national laboratories to learn from these events and adapt for the future.

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Thank you Madam Chair and I yield back the balance of my time.

Chairwoman JOHNSON. Thank you, Mr. Lucas.

And at this time if there are persons who would wish to submit a statement for the record, you're welcome to do that.

I'd like now to introduce our witnesses. Dr. Jesse Jenkins is an Assistant Professor at Princeton University with a joint appointment in the Department of Mechanical and Aerospace Engineering, and the Andlinger Center for Energy and Environment. Dr. Jenkins also leads the Princeton ZERO Lab, the Zero carbon Energy systems Research and Optimization Laboratory. He earned his Ph.D. in engineering systems and a master's in technology and policy from the Massachusetts Institute of Technology (MIT).

Dr. Varun Rai is the Walt and Elspeth Rostow Professor in the LBJ School of Public Affairs at the University of Texas (UT) at Austin. He is the Director of the UT Energy Institute and Associate Dean for Research in the LBJ School. He received his Ph.D. and his master's in mechanical engineering from Stanford University and a bachelor's degree in mechanical engineering from Indian Institute of Technology.

Dr. Juan Torres is the Associate Laboratory Director of Energy Systems Integration at the National Renewable Energy Laboratory (NREL). In this role, he oversees NREL's research to modernize and strengthen the security, resilience, and sustainability of the Nation's electrical grid. Prior to his time at NREL, he had a 27-year career at Sandia National Laboratories. Mr. Torres holds a bachelor's degree in electronic engineering technology from the University of Southern Colorado, a master's degree in electrical engineering from the University of New Mexico.

Ms. Beth Garza is a Senior Fellow with R Street's Energy and Environmental Policy Team. Ms. Garza previously served as the Director of Electric Reliability Council of Texas, Independent Market Monitor from 2014 through 2019 after serving as a Deputy Director since 2008. She is a graduate of the University of Missouri and a registered professional engineer in the State of Texas.

Last but certainly not least, Dr. Sue Tierney is a Senior Advisor at Analysis Group, an economic consulting firm located in Boston. She is a former Assistant Secretary for Policy at the U.S. Department of Energy, State Cabinet Officer for Environmental Affairs, and State Public Utility Commissioner and has more than 35 years of experience in this field. Her master's degree and Ph.D. in regional planning are from Cornell University.

I want to thank all of our outstanding witnesses for joining us today. And as our witnesses should know, you will have 5 minutes for your spoken testimony. Your written testimony will be included in the record for the hearing. When you have completed your spoken testimony, we will begin our questions. Each Member will have 5 minutes to question you as a panel.

Now we will start with Dr. Jenkins. Dr. Jenkins, you may begin your testimony.

TESTIMONY OF DR. JESSE JENKINS, ASSISTANT PROFESSOR OF MECHANICAL AND AEROSPACE ENGINEERING, ANDLINGER CENTER FOR ENERGY AND THE ENVIRONMENT AT PRINCETON UNIVERSITY

Dr. JENKINS. Thank you, and good morning. My name is Jesse Jenkins, and I must note that the views expressed in this testimony are my own and I am not speaking as a Representative of Princeton University.

I'd like to first thank Chair Johnson and Ranking Member Lucas and the Members of this Committee for inviting my testimony, and I commend the Committee for holding this hearing and for trying to get to the bottom of what went wrong in Texas during last month's extreme cold. The truth is there is plenty of blame to go around. The failures to plan for and build resilience to this extreme cold were systemic. All sources of power experienced failures from natural gas and coal plants to wind turbines and even one of the State's four nuclear reactors.

The energy crisis was not limited just to the power system. Natural gas wells and pipelines also froze, cutting off gas supply just as it was needed most. And State and Federal policymakers alike all failed to require more robust winterization measures after a 2011 storm provided ample warning of the fragility of Texas's energy infrastructure to extreme cold.

These systemic failures make it easy to cherry-pick claims that advance one's preferred narrative, but the dozens of Texans who died and the millions who suffered through the crisis deserve a full account of what went wrong. And now is the time to learn from the crisis and to take steps to prepare for the extreme weather that all Americans face, threats that climate change is making more severe.

Energy systems can and should be made more resilient with existing technology. After all, wind turbines operate today in Antarctica, gas plants in Alberta, and gas wells in Alaska. Of course, weatherizing our infrastructure comes at an added cost that must be paid back every year in the hopes that devastating but rare crises are avoided. In this way, building resilience to extreme events is a bit like buying fire insurance for your home. Most of us buy insurance not because we ever expect our homes to burn, but we know that if such a tragedy should occur, we'd lose everything, and building our lives back may be impossible. So we pay the premium every year. Determining how much insurance in the form of investment in grid resilience is worth it, and what kinds of crises we wish to protect against is thus the key question.

Answering this question is more difficult now than ever because the changing climate means the past is no longer a safe guide to the future. Extreme weather events are dangerous because our critical infrastructures are resilient only up to a point. When pushed a little bit further, a few degrees colder or hotter, an inch more rain, these systems can fail in catastrophic ways.

This is where research can make a difference. Expanded investment in climate science could help planners build more resilient systems. This research should focus on assessing impacts on critical infrastructures and identifying catastrophic failure modes.

We must also look forward to the technologies needed to build a resilient, affordable, and clean electricity system. We can see a glimpse of this feature in Texas where wind and solar provide a quarter of all electricity in 2020, more than 2.5 times the national average. Yet during this crisis, wind and solar provided at times a tiny fraction of their maximum output, leaving some to question can we assure a clean and resilient grid with a larger role for wind and solar power? The answer is yes, and to understand why, we need to understand the role of each resource in our electricity system.

We don't need every source of electricity to be reliable at all times. What we need is the system to be reliable, and that requires a mix of electricity resources all playing the right role. Wind and solar don't deliver value by being dependable. Everyone knows the wind is inconstant and the night affects solar output. Wind and solar deliver real value as fuel-saving resources. When available, these resources displace costlier sources of electricity from fuel-consuming resources like natural gas and coal. That saves billions of dollars and helps reduce carbon dioxide emissions.

What we also need is to maintain sufficient firm generating capacity to deliver necessary reliability. Firm resources are technologies that are available on-demand any time of the year for as long as needed. These characteristics make firm resources a critical complement to weather-dependent renewable energy sources, as well as resources like batteries that are best suited to fast bursts of use rather than sustained output over several days or weeks.

For instance, Princeton's Net-Zero America study, which I co-authored, finds that the United States needs to maintain a similar magnitude of firm generating capacity as we have today as the Nation makes a big but affordable transition to net zero greenhouse gas emissions.

Over the next decade existing gas capacity and nuclear reactors can act as firm resources and ensure reliability as wind and solar expand and displace coal and gas-fired generation. But reaching 100 percent carbon-free electricity systems will ultimately require sufficient clean firm capacity, and the time to invest in these technologies is now. Wind, solar, lithium ion batteries took decades to improve, including funding from R&D, demonstration and creation of early market opportunities through subsidies and standards.

This proven process of making clean energy cheap must now be replicated for a full portfolio of clean firm technologies.

In the *Energy Act of 2020*, this Committee worked on a bipartisan basis to enact critical new authorizations to advance many of these innovative clean firm technologies. More effort and investment will be required to scale up and improve these technologies in the years ahead beginning with appropriations this year to make new authorizations a reality.

Thank you for having me today, and I look forward to engaging with you on these critical questions.

[The prepared statement of Dr. Jenkins follows:]

Testimony of Dr. Jesse D. Jenkins

Assistant Professor

Princeton University

Committee on Science, Space, and Technology

United States House of Representatives

Lessons Learned from the Texas Blackouts:
Research Needs for a Secure and Resilient Grid

March 18, 2021

My name is Jesse Jenkins. I am an energy systems engineer and an assistant professor at Princeton University with a joint appointment in the Department of Mechanical and Aerospace Engineering and the Andlinger Center for Energy and Environment. I am also an affiliated faculty at the Center for Policy Research in Energy and Environment at Princeton's School of Public and International Affairs and at the High Meadows Environment Institute.

My research focuses on the rapidly evolving electricity sector, including the transition to zero-carbon resources, the proliferation of distributed energy resources, and the role of electricity in economy-wide decarbonization.

Let me first describe my professional background and qualifications. I received a PhD in Engineering Systems and S.M. in Technology and Policy from the Massachusetts Institute of Technology and a B.S. in Computer and Information Science from the University of Oregon. I have served previously as a postdoctoral Environmental Fellow at the Harvard Kennedy School and the Harvard University Center for the Environment, a researcher at the MIT Energy Initiative, a research fellow at Argonne National Laboratory, the Director of Energy and Climate Policy at the Breakthrough Institute, and a Policy and Research Associate at Renewable Northwest. Since 2012, I have also provided decision support, analytics, and policy advisory services to various non-profit and for-profit clients working to accelerate the deployment of clean energy. I have published thirteen peer reviewed journal articles as well as multiple working papers, technical reports, and policy briefs. I am one of the principle investigators of the recently-released Princeton *Net-Zero America* study and currently serve as a member of the National Academies of Science Engineering and Medicine (NASEM) Committee on *Accelerating Decarbonization of the U.S. Energy System*.

The views expressed in this testimony are my own, and I am not speaking as an official representative of Princeton University, the NASEM Committee, or any of my co-authors or consulting clients.

I would like to thank Chair Johnson, Ranking Member Lucas, and the members of the Committee for inviting this testimony. I commend the Committee for holding this hearing and for trying to get to the bottom of what went wrong in Texas during last month's extreme cold—and for working to identify what this Committee and Congress can do to better prepare all Americans for similar threats.

The truth is there is plenty of blame to go around. Failures to plan for and build resilience to this extreme cold were systemic. All sources of power experienced failures from natural gas and coal plants to wind turbines and even one of the state's four nuclear reactors. Natural gas wells and pipelines froze, cutting off gas supply just as it was needed most. And state and federal policymakers alike all failed to require more robust winterization measures after a 2011 winter storm triggered blackouts and provided ample warning of the fragility of Texas's energy infrastructure to extreme cold.

These systemic failures make it all too easy to cherry-pick claims that advance one's preferred narrative or confirm one's priors. The dozens of Texans who died and the millions who suffered through the days-long crisis – many of whom are still rebuilding today – deserve a full account of what went wrong. Americans all across the country in each of your districts can learn from the Texas crisis and take steps to prepare for the extreme weather threats we all face, threats that climate change is making more severe.

1. What went wrong

The general factors behind Texas's grid failure are now well understood—although a full timeline of all critical details on what caused specific power plant and gas system failures is still not available at this time.

What we know is that on February 14th, a rare burst of Arctic air spread across the central U.S. and into Texas, dropping temperatures there into the single digits and sending electricity demand to a new winter peak of 69,222 megawatts (MW), nearly 5% higher than both the previous record and the "Extreme Peak Load" scenario considered by the Texas grid operator, ERCOT, in its winter reliability plan.

That was before temps dropped even further overnight, sending the entire state under a winter storm warning for the first time and setting new record cold temperatures everywhere from Lubbock to Corpus Christi.

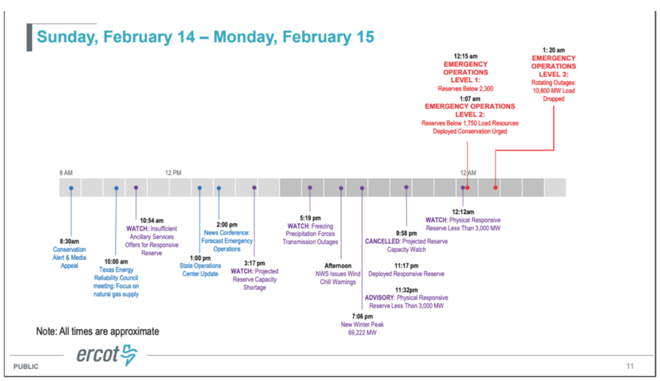

Figure 1. Timeline of the start of the Texas electricity system crisis on February 14th-15th. Source: ERCOT.

Very early on February 15th, things fell apart. Shortly after midnight, about 8,000 MW of natural gas power plants and 2,000 MW of wind turbines were forced offline by the cold.

ERCOT deployed system operating reserves, which are standby generators prepared to ramp up to compensate for this kind of unplanned outage. The system remained stable, but entered emergency operations, as now-depleted reserves left the system in a fragile state.

The next hour, 1:00-2:00am, nearly brought the entire Texas grid down. Several thousand more MW of natural gas and coal power plants failed in rapid succession. By 1:25am Monday, over 30,000 megawatts of thermal power plants were offline, more than 40% of the total needed to meet demand — and more than twice level ERCOT considered in an "Extreme Generator Outage" winter planning scenario.

Faced with record demand, depleted operating reserves, and far less generation than the "extreme" scenarios they'd planned for, ERCOT had no choice but to order transmission utilities to start emergency disconnections of millions of customers. Many of them would go without power for days.

The central challenge is that electricity supply and demand have to be kept in balance at all times. If demand exceeds supply, generators strain to meet the greater load, which results in a decline in the frequency at which the alternating current grid reverses polarity (60 hertz, or 60 times per second during normal operations) as synchronized generators slow their rotation under the strain. If the imbalance is too large and frequency drops less than 1% below the nominal 60 hertz (or less than 59.4 hertz) for more than a few minutes, generators will automatically disconnect to avoid damage, triggering a cascading failure that can result in a total systemwide blackout. A grid operator's primary duty is to avoid this outcome.

According to ERCOT, the Texas grid was just "minutes and second away" from this total system failure. If that scenario had occurred, it could have left Texans without electricity for weeks, requiring a "black start," a delicately orchestrated operation to carefully bring power plants and transmission lines back, one-by-one. While ERCOT and other system operators drill and plan for black starts, the operation has never actually been performed, as the Texas grid has never suffered a complete system-wide blackout.

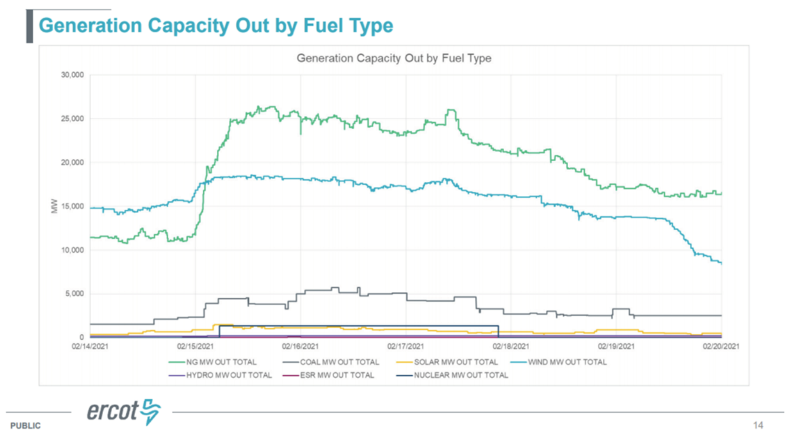

__Figure 2. Timeline of generation capacity outages reported to ERCOT.__ Note that wind and solar power capacity outages are reported against maximum rated capacity, but ERCOT does not plan on wind or solar resources to supply this much generation during winter peak load events. In their Winter Seasonal Assessment of Resource Adequacy (SARA) report, ERCOT 'derates' wind capacity to about 25% of installed capacity on average (varying by location) and solar to 7% on average, and it plans for as little as zero solar and less than 6% of installed wind capacity in 'extreme' low wind output scenarios. ERCOT also plans for about 4,000 MW of planned maintenance outages for thermal power plants (natural gas, coal and nuclear) during winter peak demand periods; 32,000 MW of thermal outages were reported at maximum. Source: ERCOT

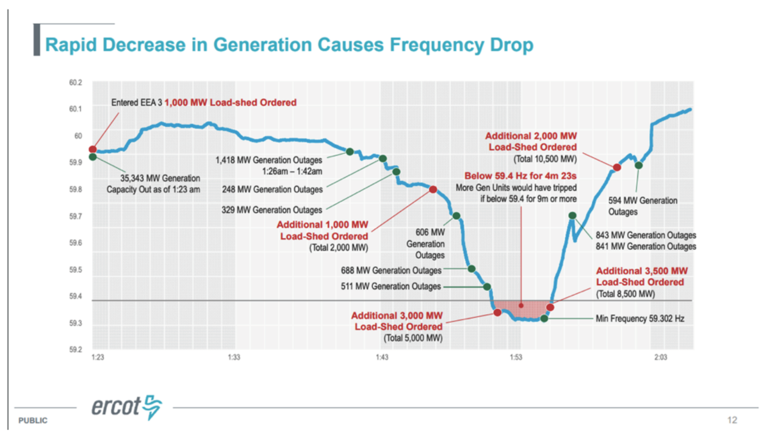

__Figure 3. ERCOT system frequency (in hertz) during the height of the grid crisis, circa 1:00-2:00am, February 15th.__ If alternating current frequency drops less than 1 percent below the nominal 60 hertz (or less than 59.4 hertz) for more than a few minutes, generators will automatically disconnect to avoid damage, triggering a cascading failure that can result in a total systemwide blackout. Source: ERCOT

The specific causes of generator outages during the night of February 15th remain unknown, as investigations continue and we wait for ERCOT to release more detailed reports on what triggered plant failures, where, and when. These details will be critical to precisely diagnose the chain of events and understand where along that chain interventions could have prevented the blackouts.

We do know that all sources of power generation were hammered by the storm, and all failed to some degree.

Wind turbines and coal piles iced up. Other power plants were knocked offline by frozen feedwater pipes, instrumentation, valves, and other equipment. For example, one of the state's four nuclear reactors, a 1,300 MW reactor at the South Texas Station half way between Houston and Corpus Christi, went offline for about 36 hours due to a frozen sensor on a feedwater pipe that supplies coolant water for the plant, triggering faulty sensor readings that forced a precautionary shutdown of the reactor. There was no real imminent danger, but reactor operators are extremely cautious, requiring the shutdown until the instrumentation could be restored.

Critically, the energy system failures were not the power grid's alone. Texas's abundant but liquids-rich natural gas fields saw wells and gathering lines freeze up, which cut gas field production in the state in half. Dozens of compressor stations along the gas pipeline system built during Texas's recent natural gas boom apparently failed to register with the transmission utilities as "critical loads," and many thus lost power during the blackouts, further exacerbating the gas supply shortages. Gas delivery pipelines can also freeze off, as water in the lines turns to ice, causing pressure swings that force pipelines to shut down to ensure safety.

The greatest share of power generation outages were at natural gas power plants, which the state relies on for about two-thirds of its winter peaking capacity. How much of this capacity was lost due to failures in gas supply wells and pipeline networks and how much was due to failures at the power plants themselves is still not clear. But what is clear is that this loss of over 26,000 MW of gas-fired capacity was the single biggest contributor to the Texas blackouts.

2. **The cost of extreme weather and the value of resilience**

In the end, a state known for its abundant energy resources experienced widespread failures of natural gas and electricity systems that left more than 4.5 million Texans without power, most of them for several days. The winter storm, the coldest in 30 years, left dozens dead and caused about $155 billion in damages and economic losses ($130 billion in Texas), according to estimates from AccuWeather. That rivals the economic toll of Hurricane

Harvey in 2017, and is nearly 2.5-times larger than the cost of the entire Atlantic basin hurricane season.

With such a devastating toll, the Texas blackouts are a tragic reminder of the sometimes-deadly fragility of our critical infrastructure systems during extreme weather conditions.

The challenge is that critical infrastructure is resilient *only up to a point.* When pushed a little bit further – a few degrees colder or hotter, an inch more rain, a day longer drought – these systems can fail in catastrophic ways. Investment and action to push back that point of failure – and to prepare response strategies that mitigate the harms when systems do fail – can be well worth it.

Extreme weather tends to cause multiple parts of critical systems to fail at the same time. These kinds of simultaneous (or correlated) failures are far more probable and dangerous than one might think. If 10 power plants each have a 10% chance of failure but these probabilities are all independent, the chance that they all fail simultaneously is infinitesimal (0.00000001%). A 1% chance (equal to the probability of a once-in-a-century storm) that 10 power plants all fail at once is far more worrisome.

Building resilient infrastructure means paying close attention to extreme events that can slam large parts of the system all at once, whether that's a winter storm, wildfire, hurricane, or flood.

While the scientific jury is still out on whether these 'polar vortex' cold snaps are related to climate change, we do know that climate change increases the frequency of extreme heat waves, droughts, wildfires, rainfall events and coastal flooding. And it is these extreme events that test our systems to the breaking point, just as they did in Texas last month.

This is the Science & Technology Committee, so questions of R&D and new innovations will deservedly be at the center of discussion during today's hearing. But at some level, the Texas crisis was not a failure of technology, per se.

Energy systems can and should be made more resilient to extreme weather with existing technology. After all, wind turbines operate today in Antarctica, gas plants in Alberta, and gas wells in Alaska.

Weatherization can be costly, but the most affordable steps, such as winterizing wind turbines or using heat tracing to keep pressure sensors from freezing up at natural gas or nuclear power plants, can be well worth it.

More costly measures could include burying gas-field gathering lines to insulate against the cold surface and housing gas wells and liquids separation facilities in heated buildings. "Dual fuel" power plants can switch from gas to petroleum stored on site when gas supplies are disrupted. Long-distance power lines can link up with far away regions facing less severe challenges.

All of this is possible with current technology, but all of it comes at an added cost, a cost paid every year in the hopes that devastating but rare crises are avoided.

In this way, building resilience to extreme events is a bit like buying fire insurance for your home.

Most of us buy insurance not because we ever expect our home to burn down. But we know that if such a tragedy should occur, however rare, the results would be catastrophic. Without insurance, we'd lose everything and building our lives back may be impossible. So, we pay the premium every year, even though we don't ever expect to use it.

If a crisis does strike, paying the premiums can look like the perfect decision in hindsight.

The problem, of course, is that we have to plan using our foresight, not hindsight. Determining how much 'insurance' – in the form of investment in grid resilience – is worth it and what kinds of crises we wish to protect against is the key challenge.

Texas is well prepared for summertime peaks in demand driven by heat waves, just as New England is well prepared for winter cold and gas supply shortages. These happen frequently enough that it's clear we must make investments to mitigate these risks. Planning for rarer events is much more difficult.

But just as with the decision to purchase fire insurance, the calculus should come down to not only how frequent such events are but also *how severe their impacts are when they occur*. A once-in-a-decade cold snap or heat wave that causes a few hours of rotating blackouts may be something we can live with. But as the Texas crisis reveals, several days without power and heat during sub-freezing temperatures costs far too much in both lives lost and economic damages incurred.

The changing climate makes planning and building resilience more difficult, as it means the past is no longer a safe guide to the future. The entire country must get much better at preparing for the unexpected.

Going forward, any new infrastructure we invest in should be prepared for not only today's climate, but also the climate we'll have decades into the future. For each upgrade we make, we must decide what range of climate extremes it should be able to withstand.

This is where research can make a difference. Expanded investment in climate science could help planners build more resilient systems. The focus of this research should be on assessing impacts on critical infrastructures and proactively identifying failure modes that can bring correlated or simultaneous failures of the kind experienced in Texas.

3. Building a resilient and affordable clean electricity system.

The U.S. electricity system in transition. About half of all U.S. electricity sales are now covered by states or electric utilities that have now committed to transition to 100% clean electricity. Federal legislation requiring a transition to 100% clean electricity nationwide has also been introduced. The direction of travel towards a 100% carbon-free grid is clear, even if the pace remains uncertain.

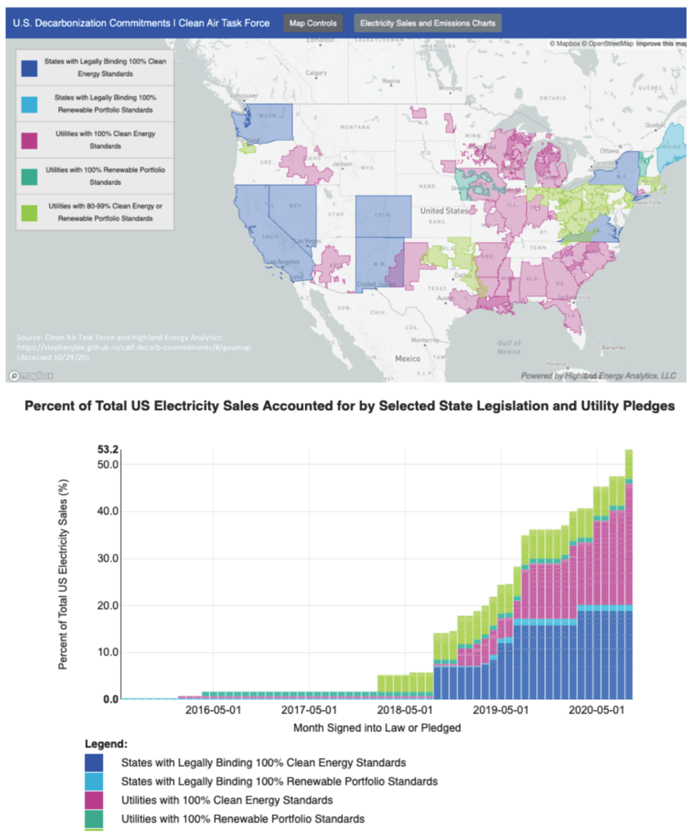

Figure 4. States with legally binding 100% clean energy or renewable energy requirements and utilities with voluntary commitments to transition to overwhelmingly clean electricity supplies. *These commitments now cover about half of all U.S. retail sales of electricity. Source: Clean Air Task Force and Highland Energy Analytics.*

This transition is critical, because clean electricity is the linchpin in any successful and affordable transition to a net-zero emissions U.S. economy by 2050 or sooner. As the National Academies study on *Accelerating Decarbonization of the U.S. Energy System* makes clear, pathways to cost-effectively reach net-zero greenhouse emissions entail twin challenges for the electricity sector:

1. As the source of more than a quarter of U.S. greenhouse gas emissions and with multiple scalable, affordable alternatives to fossil fueled power plants available today, the electricity sector must (and can) cut emissions faster and deeper than any other sector.

2. Electricity generation must substantially expand—approximately 10−20% by 2030 and 120−170% by 2050—to fuel a greater share of energy use in transportation, building space heating, and low- and medium-temperature industrial process heat as well as produce hydrogen from electrolysis and even power direct air capture.

Rapidly reduce greenhouse gas emissions and transitioning to net-zero emissions nationwide is a critical and achievable goal. Until we reach net-zero emissions globally, the concentration of climate-warming gases will continue to increase, destabilizing our weather and driving more frequent and severe extreme events that are electricity systems and other critical infrastructure are so vulnerable to.

The U.S. can and should lead in this transition. We have the economic and technical means to do so, and our leadership can not do our part to reduce our share of global emissions, but can also serve to drive the American ingenuity and innovation that will make clean energy and climate solutions affordable and available for the world.

The Princeton *Net-Zero America* study, for which I served as co-principal investigator, concluded that this transition to net-zero emissions and 100% carbon-free electricity is an enormous national undertaking, but one that is ultimately affordable.

We modeled and analyzed with unprecedented granularity five distinct pathways to affordably reach net-zero economy-wide by 2050. These paths all rely on technologies we fundamentally know how to build today, although several require continued innovation and cost declines to realize their full potential, and none depend on widescale behavioral changes such as shifts to vegetarian diets or major reductions in vehicle travel.

The *Net-Zero America* study concludes that all of these paths to net-zero emissions require spending no more (and in many case less) as a share of our national gross domestic product on energy services as we do today. In other words, getting to net-zero does not require widespread economic sacrifice or a World War Two style mobilization of 20% of our GDP to build a clean energy infrastructure. Instead, we need to continue spending about the same amount of our household and business expenditures on energy as we do today, but shift our investments towards cleaner sources of electricity and other energy sources.

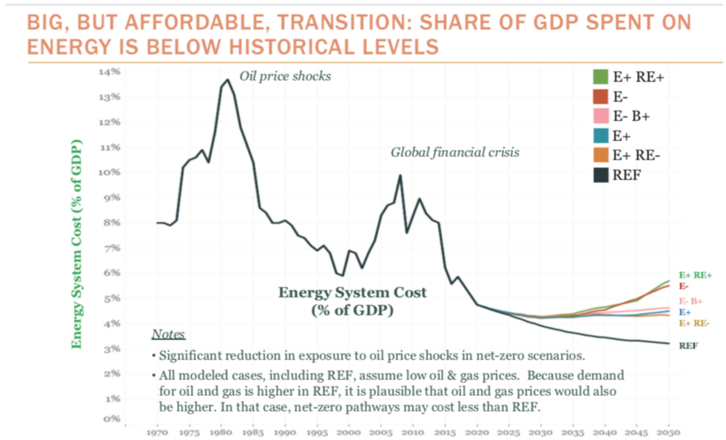

Figure 5. Annual energy expenditures as a share of U.S. gross domestic product (GDP) under five modeled pathways to net-zero greenhouse gas emissions economy-wide by 2050. *Source: Princeton Net-Zero America study.*

The benefits of this transition are also large, including half a million to a million *net* jobs created in energy supply related sectors by 2030 and 2-3 million by 2050, as well as $2-3 trillion dollars in public health damages and 200,000-300,000 premature deaths from air pollution avoided from 2021-2050.

The findings of *the Net-Zero America* study should build confidence that by deploying the clean energy technologies we have today *and* continuing to drive the innovation and improvement in technology that this committee has worked so hard to accelerate, we can reach net-zero while spending a similar share of GDP on energy services as we do today.

Our modeling for the *Net-Zero America* study and most other research on electricity systems today repeatedly finds that wind and solar power can be cornerstones in an affordable and clean electricity system.

Wind and solar power are now cheap. Thanks to proactive public policy support and innovation, the cost of wind power has fallen by about 70% and the cost of solar by about 90% over the last decade alone, and cost declines are projected to continue into the future. This increasingly makes wind and solar the cheapest source of electricity we can use, period.

Yet during the Texas crisis, wind and solar power provided at times as little as 1,000 MW of output, a tiny fraction of the more than 30,000 MW of installed capacity. That performance during the winter storm has led some to question: Can we assure a clean *and* resilient grid with a larger role for wind and solar power?

The answer is yes. To understand why, we need to understand the role of each resource in the electricity system.

We don't need every source of electricity to be reliable all the time. What we need is the *system* to be reliable, and that requires a mix of electricity resources all playing the right role on the electricity team.

Wind and solar don't deliver value by being dependable, and this should come as no surprise to anyone.

The simple truth is that wind and solar are reliably unreliable. We *know* the wind is inconstant and that nights affect solar output. Grid planners, including ERCOT, thus heavily discount the contribution of wind and solar during peak demand or extreme weather conditions. And they should.

The fact that wind and solar are unreliable does *not* mean they have no value. This simply isn't their job.

Wind and solar deliver real value to electricity systems and ratepayers as fuel-saving resources. When available, wind and solar power are the cheapest ways we have to produce electricity. Without fuel, they are nearly free on the margin; when the wind is blowing and the sun is shining, these resources displace costlier sources of electricity, namely from fuel consuming resources like natural gas and coal. That saves billions of dollars and helps reduce the carbon dioxide emissions fueling more extreme weather that threatens the resilience of our electricity systems.

Remember that Texas has no mandate for wind or solar power. The state was one of the first states implement a renewable portfolio standard in 1999, requiring 5,000 MW of wind power by 2015 and 10,000 MW by 2025, but Texas surpassed this 2025 target fourteen years early in 2009. Since then, every single megawatt of wind or solar power installed in the state has been installed because it makes more money for its investors and saves more money for Texas electricity consumers than any alternative. Wind and solar aren't chosen because of onerous regulations, but because they make economic sense.

What every power system with a bigger role for wind and solar need is to maintain sufficient firm generating capacity to deliver necessary reliability.

Firm electricity resources are available on demand, any time of the year, for as long as needed.[1]

These characteristics make firm resources a critical complement to weather-dependent variable renewable energy sources like wind and solar power, as well as resources such as batteries or strategies like demand flexibility (which permits consumers to reduce their electricity use in periods when supplies are strained) that are best suited to fast bursts of use, rather than sustained output over days or weeks.

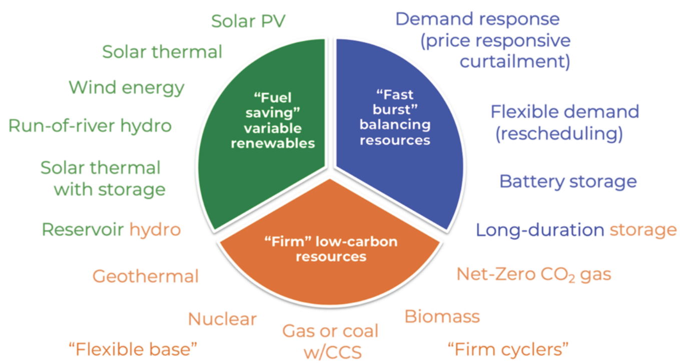

Figure 6. A taxonomy of low-carbon electricity resources. *"Firm" low-carbon resources are available on demand, any time of the year, for as long as needed, and are a critical complement to weather-dependent fuel-saving variable renewables and limited-duration "fast burst" balancing resources like batteries. Source: Sepulveda, Jenkins, de Sisternes & Lester (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," Joule 2(11). Full paper pdf at http://bit.ly/FirmLowCarbon*

The U.S. has about 950 gigawatts (GW) of firm generating capacity installed today, primarily natural gas (547 GW), coal (238 GW), and nuclear (101 GW) power plants.

Going forward, modeling for Princeton's *Net-Zero America* study finds that the U.S. needs to maintain between 500 and 1,000 GW of firm generating capacity as it transitions to net-zero greenhouse gas emissions and a 100% carbon-free electricity system.

[1] Sepulveda, Jenkins, de Sisternes & Lester (2018), "The role of firm low-carbon resources in deep decarbonization of electric power systems," *Joule*. https://doi.org/10.1016/j.joule.2018.08.006

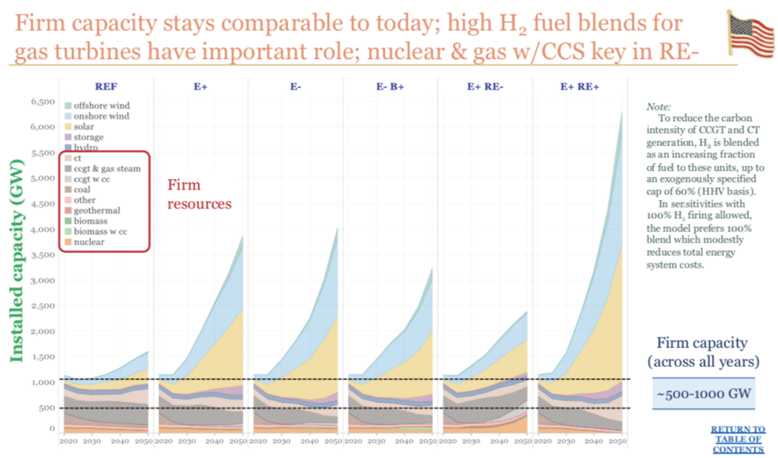

***Figure 7. Clean firm capacity requirements in the Princeton Net-Zero America**. Five net-zero emissions pathways for the United States and a reference case with no new policies are presented. Between 500-1000 GW of firm capacity is maintained in all cases, including a mix of combustion turbines and combined cycle power plants running on 60-100% hydrogen blend, natural gas and biomass-fired power plants with carbon capture, and nuclear power plants. This compares to about 950 GW of firm capacity in the U.S. grid today, mostly from natural gas and coal power plants. Source: Princeton Net-Zero America study.*

Over time, the U.S. therefore needs to scale-up a range of sources of clean firm power.

Clean firm resources are firm generation sources that can produce electricity with zero or near-zero emissions of greenhouse gases. This includes:

- nuclear power plants;
- coal or natural gas-fired power plants that capture and permanently store carbon emissions (carbon capture and sequestration or CCS);
- use of hydrogen or other zero-carbon fuels in combustion turbines or fuel cells;
- geothermal energy; and
- biomass power plants that capture and store carbon emissions.[2]

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[2] Some hydro dams with very large reservoirs capable of seasonal storage can substitute for firm generation. Ultra-low cost long duration energy storage technologies with storage capacity costs in the range of $1-5/kWh and with suitable power cost and efficiency combinations can also *partially* substitute for or reduce the need for firm generation capacity. See Sepulveda, Jenkins, Edington, Mallpragada & Lester, (2021), “The design space for long-duration energy storage in decarbonized power systems,” *Nature Energy* (forthcoming).

Over the next decade, ample existing natural gas capacity and existing nuclear reactors can act as firm resources and ensure reliability as wind and solar power expand and displace coal and gas-fired generation. That means that CO_2 emissions in the electricity sector can be reduced over the next decade by 70-80% by (1) phasing out coal-fired power plants; (2) maintaining existing nuclear and gas capacity; (3) reducing the total generation from natural gas power plants; and (4) increasing electricity generation from wind and solar power to roughly 50% of U.S. electricity (up from ~10% today).

Reaching 100% carbon-free or deeply decarbonized electricity systems sometime after 2030 will ultimately require some combination of (1) replacing existing fossil-fueled firm capacity with new clean firm capacity; (2) retrofitting existing fossil capacity to capture carbon emissions or (3) converting gas power plants to use zero-carbon fuels such as hydrogen.[3] New clean firm capacity will also be needed to replace any aging nuclear power plants that retire in coming years.

The time to invest in clean firm power technologies is now.

All clean firm generation technologies are all less mature and/or more costly today than is required for widespread and affordable use. This includes: small modular and advanced nuclear reactors; advanced geothermal (such as enhanced geothermal systems or closed loop geothermal); large frame combustion turbines capable of burning 60-100% hydrogen (and technologies for affordably producing hydrogen without CO_2 emissions); biomass gasification plants; Allam-Fetvedt cycle power plants; and post-combustion carbon capture systems for fossil and biomass fueled power plants.

As this Committee knows, it takes time to improve, scale-up, and drive down the cost of novel energy technologies. Wind power, solar photovoltaics, Lithium-ion batteries, LEDs, and even hydraulic fracturing all required a decade or more of proactive public policy support — including funding for R&D, demonstration projects, and the creation of early market opportunities. These efforts transformed these technologies from expensive 'alternative technologies' to affordable mainstream options. This proven process of making clean energy cheap and scalable must now be replicated for a full portfolio of clean firm generation technologies.

What is needed now is proactive investment over the next decade in R&D, first-N-of-a-kind deployments, and early market scale-up, to ensure several clean firm technologies are affordable and ready to deploy 100s of gigawatts of capacity in the 2030s and 2040s.

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[3] Alternatively, some gas-fired generating capacity could be maintained as firm capacity and used very infrequently, *if* the CO_2 emissions from these generators are offset by negative emissions technologies that permanently store CO_2 from biomass or direct air capture in geologic formations. That would make these generators net-zero emissions firm resources. Note that storage of carbon in the 'shallow' carbon cycle in the terrestrial biome (e.g. forestry or land use offsets) is not an equivalently secure form of negative emissions as geologic storage.

In the Energy Act of 2020, this Committee worked on a bipartisan basis to enact critical new authorizations to advance many of these innovative clean firm technologies, including advanced nuclear reactors, carbon capture, hydrogen, geothermal energy, and fusion technologies.

More effort and investment will be required to scale up and improve these critical clean firm technologies in the years ahead, beginning with appropriations this year to make the new authorizations in the Energy Act of 2020 a reality.

And as the Texas crisis should show us all, we must ensure that these firm resources are *actually firm*.

Firm resources are the resources we count on to be there when we need them. If they fail us – as the natural gas, coal, and even nuclear power plants did in Texas – that is when true disaster strikes.

Innovation and research should thus focus on ensuring we have adequate and *truly firm* capacity to secure a reliable, resilient, and carbon-free electricity system.

Thank you for having me today. I look forward to engaging with you on these critical issues.

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Dr. Jesse Jenkins is an assistant professor at Princeton University with a joint appointment in the Department of Mechanical and Aerospace Engineering and the Andlinger Center for Energy and Environment and courtesy appointments at the School of Public and International Affairs and the High Meadows Environmental Institute. He is a macro-scale energy systems engineer with a focus on the rapidly evolving electricity sector, including the transition to zero-carbon resources, the proliferation of distributed energy resources, and the role of electricity in economy-wide decarbonization. Jesse leads the Princeton ZERO Lab (Zero-carbon Energy systems Research and Optimization Laboratory), which works to improve and apply optimization-based energy systems models to evaluate low-carbon energy technologies and generate insights to guide policy and planning decisions in national and sub-national jurisdictions transitioning to net-zero emissions energy systems. Jesse earned a PhD in Engineering Systems and a Masters in Technology & Policy from the Massachusetts Institute of Technology and worked previously as a postdoctoral Environmental Fellow at the Harvard Kennedy School.

Chairwoman JOHNSON. Thank you, Dr. Jenkins.
Dr. Varun Rai.

**TESTIMONY OF DR. VARUN RAI,
ASSOCIATE DEAN FOR RESEARCH;
PROFESSOR OF PUBLIC AFFAIRS,
LBJ SCHOOL OF PUBLIC AFFAIRS
AT THE UNIVERSITY OF TEXAS AT AUSTIN**

Dr. RAI. Thank you, Chair Johnson. Good morning, everyone. Good morning to Ranking Member Lucas and other Members of the Committee. My name is Varun Rai. I'm a Professor at the University of Texas at Austin, and thank you for the opportunity to appear before you for this important hearing.

I live in Austin, Texas. Texas-wide power outages started early morning on the 15th of February, affecting more than 4 million homes and businesses over 3 days. Inside our house, the temperature went down into the 30's for several days. It was like living inside of a refrigerator for days. Sadly, some of my fellow Texans died due to the crisis and aren't around to tell their tales.

There were three key contributors to the severity of the impact. First, equipment in both power generation and gas production systems froze. After another blackout in Texas in 2011, winterization of both power and gas equipment was identified as a high-priority item. Some changes were made based on those recommendations, but most standards are requirements tied to operational performance in extreme cold were set. This has meant that there is insufficient overall investment in winterization of the energy system in Texas.

Second, there were gaffes in communication and coordination. As part of ERCOT's load shedding, power to many oil and gas field operations were shut down, which meant a further strain on gas production on top of declines in production due to the weather. Power was also lost at water treatment and pumping facilities across the State. On the customer side, there was an absolute lack of coordinated, consistent, and timely emergency communication to the people of Texas. This translated the extreme weather-induced stress on the power system into a severe humanitarian crisis.

Third, even with clear warning of a severe weather event days and even weeks ahead, there were not enough calls in advance to reduce demand and conserve energy, including both electricity and gas. In my view, not mobilizing enough voluntary demand reduction during the weather event was the single biggest lost opportunity to minimize the impacts of the crisis.

Looking ahead, to learn fully from the Texas power crisis of February 2021 there are five questions that need further and immediate research to support decisionmaking. Over 4 million homes and businesses in Texas lost power during the crisis. Power outage led to a water crisis. The power and water failures put millions of Texans under extreme physical, mental, and financial stress. The load sheds were based on unsophisticated critical-load lists, which did not account for infrastructure interdependency, thus we need research and—to design load-management strategies to minimize extreme stress for households , taking into account the interdependent nature of critical infrastructure and implications for fairness and equity.

Some early estimates put the damages and economic losses upwards of $100 billion. The full scale and scope of costs and losses are multifaceted, for example, damages to water infrastructure and loss production at manufacturing facilities and bankruptcies of companies and local utilities and local governments. We should consider all these factors when evaluating the benefits and costs of infrastructure investments. There is critical need to support research that advances a more robust and comprehensive accounting and understanding of the full scale of damages that result from extreme events.

As I mentioned before, one of the biggest failures in the days leading up to the event was how poorly the demand side was engaged. Demand flexibility, both programmatic and voluntary, will inevitably need to play a much larger and effective role in the future to maintain system reliability in the face of extreme events. Achieving that flexibility at very large scale and over short timeframes of hours and days is an important area of further research.

To outside observers, during much of the crisis there was very little information and data about the status of the system and how it might evolve. People were not just in power darkness; they were also in information darkness. To address this, there is a need to design data-sharing mechanisms and collaborative efforts, including researchers at universities and national labs with appropriate data-governance mechanisms to enable monitoring, analysis, feedback, and problem-solving by the broader community around and during crises.

With the frequency of extreme weather events expected to increase as impacts of climate change unfold further, the need to understand the long-term benefits and cost of connecting ERCOT to the U.S. Eastern and Western grids is also immediate. In particular, we need research that accounts for climate-induced stresses on the energy system, systemwide vulnerabilities and options, changing energy mix, and changing nature of demand.

Thank you again for the opportunity to present at this hearing, and I look forward to the discussion.

[The prepared statement of Dr. Rai follows:]

Testimony before US House of Representatives Committee on Science, Space, and Technology

Varun Rai
Walt and Elspeth Rostow Professor of Public Affairs
Director, Energy Institute
University of Texas at Austin

March 18, 2021

Good morning Chairwoman Johnson, Ranking member Lucas, and other members of the Committee. My name is Varun Rai. I am a Professor of Public Affairs and Mechanical Engineering at the University of Texas at Austin. Thank you for the opportunity to appear before you for this important hearing.

I live in Austin, Texas and even before the major weather conditions hit broadly in Texas on Sunday, 14th February 2021, in Austin we had icing conditions since Thursday, 11th February. As a result, parts of Austin lost power starting Thursday. Texas-wide power outages started early morning of Monday, 15th February, eventually affecting 20 Gigawatts (GW) of load – about a quarter of the estimated peak demand (77 GW) – and more than four million customers over three days. In the neighborhood I live, we lost power for nearly a week followed by loss of water supply for four days. We have an electric stove – so normal cooking was disrupted as well. But we have a gas fireplace and gas heating. Of course, the gas heating didn't work because electricity is needed for the furnace controllers and for the fan. We were burning wood and cooking food in the gas fireplace for nearly a week. Inside our house the temperature went down into the 30s – like living inside of a refrigerator for days. We live in a modern, well-insulated house. Such passive weatherization becomes extremely critical in crises like this. At least we could live inside for a little bit longer, under layers of warm clothing, and not die of hypothermia. Sadly, some of my fellow Texans died due to the crisis and aren't around to tell their tales. For the rest, just the bill for the power supplied *during* the week of the crisis is estimated to be around $50 billion. The reasonableness and validity of this cost is being hotly debated by Texas policymakers currently, but if it holds, just one week's power bill for the overall Electric Reliability Council of Texas (ERCOT) market is equivalent to about three years of the market's typical power bill, so about 150 times higher than normal and roughly equivalent to $5000 per meter (household) in the ERCOT territory. I grew up in India in the 1980s and 90s, where we were used to *daily* power and water outages. But for all the years I spent in India, before I came to the US at the age of 21, there was nothing of this scale. This one beats them all.

There were three key contributors to the severity of the impact:

First, equipment, in both power generation and gas production systems, froze. This was indeed a very severe winter event, but not one without precedent. After another blackout in Texas in 2011, winterization of both power and gas equipment was identified as a high priority item[1]. Some changes were made based on these recommendations, but no standards or requirements tied to operational performance in extreme cold were set. While operators have financial incentives to winterize equipment, what makes short-to-medium term financial sense for plant operations doesn't add up to system-level reliability expectations. Relatedly, there is an issue of coordination failure: a natural gas plant owner needs to know that gas will reach the plant, and an owner of a wind farm that transmission lines will not fail. The need, but not requirement, to winterize the entire system means that, individually, owners of separate assets shy away from taking action, since they expect that others may not act either. This has meant that there is insufficient overall investment in winterization of the energy system in Texas, exposing the system to massive failure events – as we saw happen last month.

Second, as we know now, there were gaffes in communication and coordination. One of the more harmful mistakes was that as part of ERCOT's load shedding (i.e., deliberate shutdown of power to parts of the system), power to many oil and gas field operations was shutdown[2], which meant a further strain on gas production on top of declines in production due to the weather. This meant less gas for power generation, more load shedding, and more disruptions to gas plants – a vicious cycle. Power was also lost at water treatment and pumping facilities across the state. Gas, power, and water are an integrated, interacting set of systems that need to work in sync to deliver human wellbeing. Critical infrastructure is not a matter left to individual market participants. Wellbeing under extreme conditions depends on reliable functioning of critical infrastructure and coordination should be guaranteed. On the consumer side, there was an absolute lack of coordinated, consistent, and timely emergency communication to the people of Texas. Households and communities were clueless about what was happening, how to respond, and what to expect next. At the household level, it was utter chaos. We have an expansive infrastructure and significant spending in the U.S. for accurate weather forecasts to enable better emergency preparedness and communication. What we witnessed in Texas in mid-February 2021 is that even with reliable weather forecasts days in advance, the ball was dropped in assessing and conveying the urgency and direness of the situation. This translated the extreme weather-induced stress on the power system into a severe humanitarian crisis.

Third, even with clear warning of a severe weather event days and even weeks ahead[3], there were not enough calls in advance to reduce demand and conserve energy. Calls for voluntary conservation (i.e., reduced electricity and gas usage at homes and other facilities) leading up to the weather event and during it came too little, too late. A prudent approach when such events are expected in advance is to simulate the event's impact, foresee major supply disruptions and demand spikes, and ring the alarm bells. A coordinated and clear extreme conservation call – not just last-minute emails and texts – could have reduced the supply-demand gap substantially, enabling rotating outages, while relieving supply to catch up. Clearly, in the days preceding the severe weather event, and with the severity of the weather event in sight, there was gross underestimation of the scale of supply disruptions and demand increase. In my view, not mobilizing enough voluntary demand reduction (for both electricity and gas) during the weather

[1] FERC & NERC Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011.
[2] Texas House hearings, as reported by CBS Austin.
[3] Bill Magness, Review of February 2021 Extreme Cold Weather Event – ERCOT Presentation.

event was the single biggest lost opportunity to minimize the impacts of the crisis. Voluntary demand reduction is typically not a reliable strategy for balancing the grid. But this was not a typical situation. It was an unprecedented disruption to the power system and it called for extraordinary measures to manage it. Timely and coordinated communication is the key to get people ready for a situation like this. People board up or evacuate to get ready before hurricanes. If people were communicated with what was coming, would they do anything differently regarding their electricity and gas consumption during the event? Yes, they would.

Looking ahead, to learn fully from the Texas power crisis of mid-February 2021 there are five questions that need further and immediate research to support decision making. The answers will enable the design and development of reliable, yet economic, electricity systems at the state and federal levels:

1. *What are load management strategies that minimize societal damage, while upholding equity and fairness during crises?* Over four million customers in Texas lost power during the crisis. The power outages lasted two or more days as 20 GW of load was ordered shed to prevent instability on the grid. The power outage led to a water crisis, with large parts of Texas left without a water supply or under boil water notices for several days and even weeks. The interdependent, cascading failures in the gas, electricity, food, transportation, and water systems that led to days of power and water failures put millions of Texans under extreme physical, mental, and financial stress. The load sheds were based on unsophisticated critical-load lists, which did not account for infrastructure interdependency[4]. Implementation was largely binary: entire subnetworks were either on or off. We need research to design load management strategies, including the sequencing of load shedding and the placement of strategic power backups, to minimize extreme stress for households, taking into account the interdependent nature of critical infrastructure and implications for fairness and equity.

2. *What is the full scale of the economic damages due to large-scale crises like the one in mid-February 2021 in Texas?* The scale of the maximum load shed (20 GW) was five times larger than what was shed (4 GW) due to the blackouts in Texas in February 2011 and lasted much longer (70 hours vs. 7 hours)[5]. One measure of the economic damage is the *Value Of Lost Load (VOLL)* – currently capped at $9000/MWh in the Texas electricity market (note: typical average price in the Texas market is between $20-$40/MWh). Using this metric implies roughly a $10 billion value of lost load (10-20 GW load shed for ~70 hours). But this is a very conservative estimate. Other, more comprehensive, estimates put the damages and economic losses upwards of $100 billion[6]. The $50 billion power bill across ERCOT during the crisis I mentioned before and the VOLL estimates do not capture the full scale and scope of costs and losses, which in crises as wide and long as this one might dwarf the more direct bill costs or VOLL. For example, the power failure led to widespread water damage across the state, damaging both municipal and household water infrastructure (e.g. pipes), equipment (e.g., water heaters), and flooding and other water damage inside homes. There are direct costs to repairing these damages. Moving forward, households across Texas will also likely face higher insurance rates. Other damages, sometimes overlapping, include bankruptcies of companies and local governments, lost wages

[4] Texas House hearings, as reported by CBS Austin.
[5] Bill Magness, Review of February 2021 Extreme Cold Weather Event – ERCOT Presentation.
[6] AccuWeather (Mar. 5, 2021): Damages from Feb. winter storms could be as high as $155 billion.

and jobs, and damage to health and life. And there is more: lost production at semi-conductor facilities; loss of trust in the electricity system, making people hesitant to invest in the future, or to build factories that need stable electricity. We should consider all these costs when we consider the cost of infrastructure investments like new transmission or gas storage capacity, or regulatory requirements like winterization standards for gas production and power generation facilities. Unfortunately, data and analyses to estimate damages are lacking[7]. There is critical need to support research that advances a more robust and comprehensive accounting and understanding of the full scale of damages that result from extreme events.

3. *Can demand response be rapidly and smartly deployed at a very large scale to minimize system impacts?* In the absence of coordinated messaging demand soared rapidly as temperatures plummeted. Supplying a unit of demand typically requires 1.2-1.3 units of generation, because of losses between the point of generation and the point of consumption. Thus demand reduction becomes even more valuable in extreme conditions on the grid with major disruptions to power supply. As I mentioned before, one of the biggest failures in the days leading up to the event was how poorly the demand side was engaged. Much of the communication early on during the crisis included generic or coarse messaging (e.g., "turn down thermostat to 68 degrees"). Extreme weather conditions like the ones Texas faced in mid-February 2021 necessitate much more sophisticated approaches to engaging demand, including a mix of hardware (smart meters, smart thermostats, distributed generation/storage), market design (demand aggregation, market participation, and communication protocols), and collective voluntary action (using emergency communication, community preparation, and messaging that could elicit coordinated, large-scale response across thousands and millions of households). Demand flexibility, both programmatic and voluntary, will inevitably need to play a much larger and effective role in the future to maintain system reliability in the face of extreme events. Achieving that flexibility at very large scale and over short timeframes (hours and days) is an important area for further research.

4. *How to improve system intelligence and performance through third-party monitoring, analysis, and feedback?* During much of the crisis there was very little information and data (other than system-level aggregate data) about the status of the system, where the system might be headed, what to expect next, and how to prepare and respond for maximal personal and social safety and wellbeing. People were not just in power darkness, they were also in information darkness. In extreme and rapidly evolving crises like the one in Texas last month, system interdependencies and cascading events make real-time and predictive system intelligence quite difficult but possible with modern computing technology. During times of extreme stress in complex systems like the modern energy system, no one part of the puzzle is individually critical – all are, together. All pieces need collective awareness of their role in contributing to the problem and in solving it. Yet, the analytical and communication capabilities across the different pieces of the system, for example utilities, regulatory bodies, system operators and consumers, are also stretched to the fullest, just when the need for them is paramount. To address this, there is a need to design data-sharing mechanisms and collaborative efforts including researchers at universities and national labs, with appropriate data governance mechanisms, to enable monitoring, analysis, feedback, and problem-solving by the broader community around and during crises.

[7] LBNL Report (Nov. 2020): Case Studies of the Economic Impacts of Power Interruptions and Damage to Electricity System Infrastructure from Extreme Events.

5. *What is the societal value of connecting ERCOT to the eastern and/or western grids?* Given that ERCOT's neighboring power systems (including the Midcontinent Independent System Operator (MISO) and the Southwest Power Pool (SPP)) were also stressed during last month's extreme weather event in addition to ERCOT, it is unclear how much, if any, help could ERCOT have received if it were connected (AC ties) to the other two U.S. grids. However, with the frequency of extreme weather events expected to increase as impacts of climate change unfold further, the need to understand the long-term benefits and costs of connecting ERCOT to other grids is immediate. Impacts of future weather events might be very different across the different power systems and the ERCOT grid might get a lot of help from the other grids in such cases (and vice versa). Over the last decade all three major electric grids in the U.S. have seen a significant rise in the share of renewable energy sources, a trend that is expected to continue over the next few decades. Just on its own renewable energy is intermittent and needs to be managed, for example through complementary power generation or storage, to achieve high levels of reliability. It will be important to study how drastically increased amounts of generation from intermittent sources like renewable energy, in combination with sources that tend to fail together under extreme conditions, such as natural gas, can be made reliable economically. The value of integrating to other grids in a much higher renewable-energy penetration scenario might turn out to be very different compared to past estimates. To understand the benefits of connecting ERCOT to the eastern and/or western grids, we need research that accounts for climate-induced stresses on the energy system, system-wide vulnerabilities and options, changing energy mix, and changing nature of demand (more electrification, population change, responsive demand, including on-site distributed generation and storage).

Thank you again for the opportunity to present at this hearing and I look forward to the discussion.

Dr. Varun Rai is the Walt and Elspeth Rostow Professor in the LBJ School of Public Affairs at the University of Texas at Austin. He is the director of the UT Energy Institute and the Associate Dean for Research in the LBJ School. Through his interdisciplinary research, delving with issues at the interface of energy systems, complex systems, decision science, and public policy, he is developing effective policy approaches to help accelerate the deployment of sustainable energy technologies globally. He has presented at several important forums, including the *United States Senate Briefings, Global Intelligent Utility Network Coalition, Climate One at Commonwealth Club,* and *Global Economic Symposium*, and his research group's work has been discussed in *The New York Times, The Wall Street Journal, Washington Post,* and *Bloomberg News*, among other venues. He was a Global Economic Fellow in 2009. During 2013-2015 he was a Commissioner for the vertically-integrated electric utility Austin Energy. In 2016 the Association for Public Policy Analysis & Management (APPAM) awarded him the *David N. Kershaw Award and Prize*, which "was established to honor persons who, at under the age of 40, have made a distinguished contribution to the field of public policy analysis and management." He received his Ph.D. and MS in Mechanical Engineering from Stanford University and a bachelor's degree in Mechanical Engineering from the Indian Institute of Technology (IIT) Kharagpur.

Chairwoman JOHNSON. Thank you, Dr. Rai.
Mr. Juan Torres.

TESTIMONY OF MR. JUAN TORRES, ASSOCIATE LABORATORY DIRECTOR, ENERGY SYSTEMS INTEGRATION NATIONAL RENEWABLE ENERGY LABORATORY

Mr. TORRES. Chairwoman Johnson, Ranking Member Lucas, Members of the Committee, thank you for the opportunity to discuss [inaudible]. I commend the Committee for this timely hearing, as it will inform research that will help guide the Nation toward a more secure and resilient energy future. My name is Juan Torres, and I serve as the Associate Laboratory Director for Energy Systems Integration at the U.S. Department of Energy's National Renewable Energy Laboratory, or NREL, in Golden, Colorado. I've been affiliated with Federal research in our national laboratory system for over 30 years. In my current position, I direct NREL's efforts to strengthen the security resilience and sustainability of our Nation's electric grid. In addition, I'm Co-Chair for the DOE Grid Modernization Laboratory Consortium and Technical Lead for its Security and Resilience Teams.

I observed the catastrophic failures of the Texas energy system not just as a research engineer but as a concerned parent, as both of my children reside in Texas. My son works in Austin and my daughter is a graduate student in Irving. The severity of the event was clear when the conversations with them became do you have enough food, water, and blankets? Sit in your car and run it to charge your phone and get warm. Tragically, many others in the Texas community had it much worse.

It's been said that necessity is the mother of invention. I can say that we have many needs with regards to the power grid, but I'm also hopeful because we as a nation have the innovation and horsepower to meet these needs. But where do we start? First, we need to understand where we came from and where we're going. There is no single owner, operator, or architect for the U.S. power system. It is an engineering marvel influenced by a collective of stakeholders over more than a century.

Recent years have seen the grid evolve from a network based on large, centralized generation to a hybrid system incorporating more distributed renewable resources. Significant changes are also occurring at the grid edge near the consumer. Never before has a consumer been more proactive and engaged with the operation of the grid. Real-time pricing, transactive energy, smart appliances and lighting, grid-interactive buildings and smart loads, electric vehicles, and residential photovoltaics are just some of the technologies transforming the edge of the grid. And we have yet to understand the long-term energy impacts that innovations resulting from COVID–19's influence on the work-from-home culture.

Equally important is awareness of the dynamic threat space which includes not only severe weather but also physical attacks, geomagnetic disturbances, electromagnetic pulse (EMP) events, and the ever-growing cyber threat. I offer the following recommendations based on critical lessons from the recent outage in Texas and other past major storm events.

First, take actions to harden the grid and generation fleet to the broad spectrum of evolving threats for improved monitoring, planning, investments, and technology advancements.

Second, address the overall resilience of the energy system from fuel to generation, to delivery, to end-use, taking into account interdependent infrastructure such as communication systems, natural gas pipelines, and transportation systems.

Third, research how a grid with more controllable devices and increasingly high penetrations of variable renewable generation can be even more secure and resilient than today's grid.

While these challenges are considerable, research is lighting the path forward. Let me give you some examples. DOE's Grid Modernization Initiative (GMI) and the 14 national labs in the Grid Modernization Laboratory Consortium have been working with industry and academia to tackle grid research challenges over the past 5 years in devices, advanced architectures and controls, design and planning tools, generation, sensors, regulatory policy support, and security and resilience.

NAERM, the North American Energy Resilience Model, is a DOE multi-lab comprehensive modeling capability being developed to support grid planning and investment and to understand the grid's state of resilience while considering interdependencies with the natural gas and communication sectors.

ARIES, NREL's state-of-the-art Advanced Research on Integrated Energy Systems platform, is leading the way for large-scale experimentation and cyber emulation of the future grid from behind the meter to the bulk transmission system. We've only just opened the door to many new research directions.

Thank you for the opportunity to speak to you today. I look forward to any questions you may have.

[The prepared statement of Mr. Torres follows:]

Prepared Statement of Juan Torres
Associate Laboratory Director for Energy Systems Integration
National Renewable Energy Laboratory

For the U.S. House of Representatives Committee on Science, Space, & Technology
Hearing on "Lessons Learned from the Texas Blackouts: Research Needs for a Secure and Resilient Grid"

March 18, 2021

Chairwoman Johnson, Ranking Member Lucas, members of the Committee, thank you for this opportunity to discuss the importance of grid resilience and security and the research directions that we can take to prepare for future events. In my testimony, I will present on:

- The changing state of the power grid and impacts on energy security and resilience
- Some learnings from the February 2021 Texas power grid outage and other events
- Current DOE and national laboratory activities to increase grid security and resilience
- Next Steps: strengthening and expanding capabilities to establish more resilient energy systems.

My name is Juan Torres, and I serve as the associate laboratory director for Energy Systems Integration at the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory, or NREL, in Golden, Colorado. I have been affiliated with federal research and our national laboratory system for over 30 years. In my current position, I direct NREL's efforts to strengthen the security, resilience, and sustainability of our nation's electric grid. In addition, I am co-chair of the DOE Grid Modernization Laboratory Consortium (GMLC) and technical lead for the GMLC's security and resilience teams. The GMLC is a partnership of 14 national laboratories working to advance modernization of the U.S. power grid. Prior to joining NREL, I served for many years in various technical and managerial roles at Sandia National Laboratories, advancing cybersecurity, energy, and power grid research, most recently as deputy to the vice president for energy programs. Earlier in my career, I also served on the DOE task force that developed a plan to protect U.S. energy infrastructure in response to Presidential Decision Directive 63 on Critical Infrastructure Protection.

NREL was established in 1977 to advance renewable energy technologies as a commercially viable option. Over the years, our groundbreaking advanced energy research has contributed to transformational scientific advancements, exponential decreases in the cost of renewable energy, and more renewable installed capacity than ever before. We are continually looking ahead to understand how advanced technology options can enable a balanced and secure national energy portfolio. From our perspective, grid resilience is one of the most crucial and urgent energy challenges our nation must address.

The Changing State of the Power Grid and Impacts on Energy Security and Resilience

There is no single owner, operator, or architect for the U.S. power system. It is an engineering marvel influenced by a collective of stakeholders over more than a century. Predicting what the grid will look like in the future is extremely difficult given uncertainties in future policies and regulations, which are implemented at the federal, state, and local level, and rarely consistent or aligned across all stakeholders. A recent study[1] by the National Academies of Sciences, Engineering, and Medicine effectively captures the driving forces (social, technical, economic) that are likely to shape the future power grid over the next several decades. Revolutionary advances in technology are also difficult to foresee, but trends can be monitored and influenced through consistent investment.

The grid is evolving from an architecture of large, centralized generation to a hybrid system incorporating more distributed, largely variable renewable resources. Significant changes are also occurring at the grid edge, near the consumer. Never before has the consumer been more proactive and engaged with the operation of the grid. Real-time pricing, transactive energy, smart appliances and lighting, smart loads, electric vehicles, and residential photovoltaics are just some of the technologies transforming the gride edge.

Also worth noting are the increasing interdependencies between the grid and other infrastructure. For example, electrification of vehicles increases the reliance of the transportation system on electricity, and advances in telecommunications technology like 5G make it attractive for utilities to communicate with the many more devices and sensors being added to their systems.

COVID-19 has changed how and where we use energy in a way not planned or predicted prior to the pandemic. A large portion of the U.S. workforce transitioned to working from home, seemingly overnight. Electricity loads from business districts shifted to residential neighborhoods. Post-pandemic, many businesses are likely to continue maintaining a remote workforce now that they have become more savvy with the virtual experience and tools. The long-term impacts and innovations resulting from the pandemic remain to be seen.

Equally significant is the dynamic threat space. The devastating consequences of extreme weather events—economically, socially, and even tragically with loss of life—remind us once again of our reliance on the power grid and its potential fragility if we don't remain vigilant to strengthening its resilience against evolving threats. Intensifying storms, wildfires, and cyberattacks, along with physical attacks, geomagnetic disturbances, electromagnetic pulse events, and aging energy infrastructure all threaten to disrupt power for millions of Americans and overwhelm an energy system that must evolve to meet 21st-century needs.

Ultimately, stakeholders, including policy makers, regulators, grid planners, and operators, could consider the following six attributes when seeking out solutions providing multiple benefits:

- **Resilient** – Recovers quickly from any situation or power outage
- **Reliable** – Improves power quality and fewer power outages
- **Secure** – Increases protection to our critical infrastructure
- **Affordable** – Maintains costs commensurate with value to consumer
- **Flexible** – Responds to the variability and uncertainty of conditions across a range of timescales, including a range of energy futures
- **Environmentally sustainable** – Reduces environmental impact of energy-related activities.

[1] National Academies of Sciences, Engineering, and Medicine 2021. *The Future of Electric Power in the United States.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25968.

Some Lessons from the February 2021 Texas Power Grid Outage and Other Events

The February 2021 winter storm in Texas is another example of a devastating power grid outage caused by extreme weather events. We must view the Texas outage in the context of numerous other storms that have devasted areas such Puerto Rico, New Orleans, and other coastal regions over the past few decades. Additionally, winter storms and wildfires continue to cause seasonal power outages in other parts of the country.

We offer the following critical lessons from past devastating storms as guidance for improving grid resilience:

- We must take actions to harden the grid and generation fleet to the broad spectrum of evolving threats through improved monitoring, planning, investments, and research and development (R&D).
- Meeting the challenges of a resilient electricity delivery system will require fully addressing the overall resilience of the energy system, from fuel to generation to delivery to load, including interdependent infrastructure (e.g., communications systems, natural gas pipelines, and transportation systems).
- We must research how a grid with more controllable devices and increasingly high penetrations of variable renewable generation integrated with a variety of legacy and emerging resources can be even more resilient than today's grid.

Addressing these topics is a multifaceted challenge. It involves new approaches to planning and operations, new investments in infrastructure, and a targeted understanding of how distinct power systems across the country can best modernize given their particular systems and circumstances. Most of all, it involves adapting to the trends currently driving change.

But this is not unknown territory for us. As I will discuss in the following sections, research is lighting the path forward. A variety of projects have delivered results that range from cutting-edge concepts to real-world demonstrations. We can use these results to inform our approach to building more resilience.

Current DOE and National Laboratory Activities to Increase Grid Security and Resilience

Communities across the nation—from remote rural locations to major metropolitan areas—are undertaking energy system transformations centered on clean energy, electrification, and integrated solutions. As such, there are significant opportunities to modernize the grid with resilience and security as inherent features to mitigate the spectrum of evolving threats. Two major initiatives spanning DOE programs and national laboratories are vanguards in leading-edge research and impact.

Grid Modernization Initiative

DOE's Grid Modernization Initiative (GMI) was established to work with the electricity sector to address the challenges of grid modernization and leverage our national resources to drive solutions. GMI brings together the efforts of the DOE Offices of Electricity (OE), Fossil Energy (FE), Nuclear Energy (NE), Cybersecurity Energy Security and Emergency Response (CESER), and Energy Efficiency and Renewable Energy (EERE). The initiative coordinates research and development across DOE to help set the nation on an affordable path to a resilient, secure, environmentally sustainable, and reliable grid in light of the rapid changes occurring throughout the system.

As part of GMI, DOE partnered with its national labs to form the Grid Modernization Laboratory Consortium, or GMLC. The GMLC—co-led by NREL and the Pacific Northwest National Laboratory—acts as the boots on the ground to execute critical research that is already delivering solutions today, with plans to continue to do so well into the future.

DOE and its national labs, through the GMLC, have the most advanced set of grid research capabilities anywhere in the world to help guide broad grid improvements. DOE is not only applying these capabilities to carry out foundational R&D in energy security and resilience but also partnering with utilities, private industry, and local, state, and federal governments to demonstrate and deploy new technologies and concepts.

North American Energy Resilience Model

One of the most visionary efforts under GMI to look at resilience on a large scale is the North American Energy Resilience Model (NAERM). A collaboration between DOE, its national laboratories, and industry, NAERM is developing a comprehensive resilience modeling system for North American energy infrastructure, which includes the electric, natural gas, and communications sectors.

With this model in place, key actors will have real-time situational awareness and analysis capabilities for emergency events. Of equal importance, NAERM will make it possible to get ahead of emergencies before they happen. NAERM will help us transition from the current reactive state-of-practice to a new energy planning and operations paradigm in which we proactively anticipate damage to energy system equipment, predict associated outages and lack of service, and recommend optimal mitigation strategies.

In this way, NAERM serves another critical function as an infrastructure planning and investment tool. By pinpointing vulnerabilities, NAERM can also help answer questions for power grid planning and operations, such as:

- What is the next best investment that will yield contributions to national security?
- How can we improve electric and gas sector resilience to a wide range of threats?
- What are the impacts and cost-benefit trade-offs of different mitigation plans?
- Can we recommend optimal mitigation strategies to stave off large-scale system damage in real time?

NAERM has already modeled and captured different extreme events and their impacts. For example, NAERM recently modeled different polar vortices across the United States on which the team gathered historical data to understand and benchmark the impacts of cold temperatures, snow, and ice on the electric and other interdependent systems.

This allowed the team to conduct scenario analysis to ask more “what-if” questions. What if it is colder than forecasted? What if we invested in more cold weather packages? This crucial analysis and understanding of how extreme events can impact these systems and the well-being of citizens means we can work with industry stakeholders to invest, plan, and operate the grid through these types of events.

We have the research tools to guide solid decision-making at the national level. However, without regulatory, policy, and economic structures that bridge research and technical recommendations to reality, we will not be able to realize these solutions.

Current NREL-Supported Activities to Increase Grid Security and Resilience

Energy security and resilience are central to NREL's objective to develop integrated energy pathways. NREL-led work in this area primarily focuses on optimizing the safe and secure integration of renewables and energy storage, as well as controls and capabilities that support resilient operations. Much of this research happens in the Energy Systems Integration Facility, a DOE User Facility, and involves considerable participation from industry and grid operators.

Advanced Research on Integrated Energy Systems

NREL, in partnership with EERE, has developed a globally unique Advanced Research on Integrated Energy Systems (ARIES) research platform.

ARIES is designed to mirror the complexity and scale of real energy systems. Rather than evaluating new clean energy and energy efficiency technologies in silos, ARIES expands the research view to take in the full picture—from consumers to industry to utilities. This perspective uncovers opportunities and risks in the spaces where energy technologies and sectors like transportation, buildings, and the electric grid meet.

ARIES was specifically created to support the transition to a modern energy system that is clean, secure, resilient, reliable, and affordable. To get there will require new approaches to some fundamental challenges. These include coordinating many different types and sizes of energy technologies, securely controlling tens of millions of devices, and integrating diverse technologies with high amounts of renewable generation.

The ARIES platform is built to be highly flexible with the ability to plug-and-play different technologies into the core integrated system. This makes it possible to pivot and stay ahead of the rapidly evolving energy sector. It supports research of critical importance, including:

Energy storage – balance variable renewable generation and demand
Power electronics – operate and integrate rapidly increasing electronics-based technologies
Hybridization – achieve enhanced coordinated capabilities beyond isolated technologies
Infrastructure – adapt existing energy infrastructure for safety, monitoring, and controls
Cybersecurity – secure operations to prevent disruption, damage, and loss of functionality

The ARIES platform is a key tool to develop and validate energy resilience. The platform includes utility hardware—from wind turbines, solar PV and storage, to transmission lines and substations—augmented by high-performance computing and high-speed links to other DOE lab assets. All together, ARIES is a large sandbox to experiment with at-scale energy concepts such as microgrids, distribution system controls, integrated mobility, and resilience scenarios.

ARIES is also a unique capability to make progress in step with industry. As GMI mobilizes close collaboration between industry and the national labs, ARIES is the most high-power, high-impact research platform to support this work. ARIES connects industry with the equipment, modeling, and expertise needed to collaboratively design future energy systems that power the entire nation safely and sustainably.

Synchronous Interconnections

Through a series of multiyear studies, NREL has joined with national lab, university, and industry partners to evaluate the benefits and costs of options for continental transmission across the U.S. electric grid. These interconnections would create a more integrated power system that could drive economic growth and increase efficient development and use of the nation's abundant energy resources, including solar, wind, and natural gas.[2]

Currently, the three major components of the U.S. power system—the Western Interconnection, the Eastern Interconnection, and the Electric Reliability Council of Texas—operate almost independently of one another. Very little electricity is transferred between the interconnections due to limited transfer capacity. Our studies quantify the costs and benefits of strengthening the connections between these three interconnections to encourage efficient development and use of U.S. energy resources.

In one study looking at integrating the Western and Eastern Interconnections, the results show benefit-to-cost ratios reaching as high as 2.9. This indicates significant value to increasing the transmission capacity between the interconnections under the cases considered, realized through sharing generation resources and flexibility across regions. Further benefits can be realized through job creation and economic growth resulting from the required infrastructure build-out.

Work on related studies is continuing (including the North American Renewable Integration Study and Extreme Weather Event Analysis), focusing on a wider variety of scenarios and prioritizing resilience considerations.

New Operations for Diverse and Distributed Energy

One of the greatest challenges in grid modernization is the immense number of distributed energy resources that are interconnecting—and the degree of connectivity that will follow. Between electric vehicles, digital and interactive buildings, rooftop solar PV, and other resources, new energy devices could reach into the tens of millions in the near future. From a control perspective, we have never seen anything like this. From a resilience perspective, we want to know how these devices can contribute to a secure and stable power grid.

A major undertaking of GMI relates to modern controls that can leverage distributed energy resources, not only for behind-the-meter assets, but utility power plants that could include solar, wind, and storage. Compared to conventional operation, these new controls introduce resilience through adaptivity and distributed management, rather than centralized control—the advantage being that resources are aggregated, deployed, or more locally managed in real time for flexible and efficient power distribution. A couple examples of NREL-led work in this space are below:

- One GMI project, FAST-DERMS, is developing distributed controls that integrate with utilities' current management systems. These controls use real-time data from sensors and monitoring to support scalable management of energy storage and renewables, so they can provide bulk grid

[2] https://www.nrel.gov/docs/fy21osti/76850.pdf

services at least as well as conventional power plants. From the perspective of transmission system operators, these controls add flexibility without changing market operations.

- In another GMI project, FlexPower, NREL is leading a coalition of multiple laboratories and industry partners to validate hybrid power plants that combine solar, wind, and other resources with energy storage. Results from this project demonstrate how combined renewable assets can provide dispatchability[3] similar to conventional generation, improving grid reliability. In the case of this project, energy market regulation will need to advance to benefit from these findings.

Resilience Through Autonomous Systems

Within NREL, we have also been pioneering an all-new approach to power grid operations. The Autonomous Energy Systems research effort establishes a new foundation for grid organization based around dynamic microgrids. The idea is that dynamic reconfiguration can allow "cells" of the grid to island and secure their own power, or automatically reconnect to exchange power with other cells. Critically, this concept also addresses the challenge of controlling and optimizing millions of grid-connected devices. It overcomes complexity by breaking down the problem into manageable parts, built on an inherently resilient structure.

As part of the Autonomous Energy Systems effort, NREL researchers developed OptGrid, a product licensed by NREL that has industry-shifting potential to help manage today's increasingly distributed energy infrastructure. OptGrid has been trialed in rigorous lab experiments and on real power systems, and it has emerged as a commercial solution for real-time coordination of distributed energy resources. OptGrid manages energy from the bottom up, using a distributed rather than centralized approach to control devices. This shift brings real-time management to the grid edge, where devices can be leveraged for flexibility, recovery, and energy savings.

OptGrid was developed under funding from Advanced Research Projects Agency-Energy, or ARPA-E, within the Network Optimized Distributed Energy Systems (NODES) program. NREL first deployed and field-tested the NODES algorithms at a net-zero-energy affordable housing development in Basalt Vista, Colorado, in partnership with Holy Cross Energy in 2019. This technology has led to an average 85% drop in residents' utility bills. In March 2020, Utilidata announced that it had secured the rights to OptGrid, the software NREL developed from the NODES algorithms, and will commercialize it.

We continue to build out and evaluate these controls with partner utilities, which could localize the future of energy resilience in community-scale microgrids and their resources.

Microgrids as a Modern Foundation for Resilience

At a more applied level, NREL has supported the development of microgrids that are now proving to be reservoirs of power resilience.

- For example, in August 2020 during the California wildfires, several microgrids were able to independently provide power, or otherwise reduce bulk system load.[4] One of these microgrids,

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[3] https://www.nrel.gov/news/features/2020/renewables-rescue-stability-as-the-grid-loses-spin.html
[4] https://microgridknowledge.com/california-blackouts-microgrids-flexible-load/

located in the remote and weather-battered town of Borrego Springs, California, remained islanded from the local utility and operated throughout the disaster using controls derived from NREL's Autonomous Energy Systems research. This demonstrates, even under the most trying conditions, how advanced microgrid controls and local assets can provide resilient power. The Borrego Springs microgrid project also demonstrates that high-renewable microgrids can be resilient, which helps to validate operations with a broader mix of assets that includes energy storage, electric vehicles, and customer devices.

- The U.S. Department of Defense (DOD) has led early adoption of microgrids, and through our partnership with DOD, we have refined the controls and operations for live microgrid systems. A microgrid at Marine Corps Air Station Miramar that was developed in partnership with NREL is another example of a live microgrid that provided resilience throughout the August wildfires by reducing power draw from the local utility and maintaining power for its community.[5]

- We recently faced our own microgrid scenario at NREL—after an onsite device failure, we successfully repowered our Flatirons campus using renewable energy assets, storage, and in-house controls.[6] This event points to the importance of microgrid capabilities and suggests our technical validations to date have provided a sophisticated understanding of microgrid operations.

With growing interest around this topic, we have also defined potential regulatory pathways forward for microgrids.[7]

These promising examples would suggest that a more widespread application of networked microgrids that combine storage and other renewable assets could reduce community exposure to damage or generation loss and hasten recovery following a disaster by providing reliable backup power. GMI and industry partnerships continue to be valuable resources for insight around integrating microgrids, as well as the Autonomous Energy Systems program and new efforts to deploy adaptive controls.

Cybersecure Systems

With the rise in new energy technologies that are driving system configurations, operating strategies, market structures, overseas supply chains, and business models, new cybersecurity vulnerabilities are emerging.

These trends will continue to underline three grand challenges, all of which have implications for system resilience:

- The exponential increase in control system devices that are being connected to the grid
- The rise in private or third-party owners of such assets who may not have a vested interest in cybersecurity
- The loss in control and knowledge of the technology supply chain.

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[5] https://www.nbcsandiego.com/news/local/mcas-miramar-helps-san-diego-combat-rolling-blackouts/2388878/
[6] https://www.nrel.gov/news/features/2020/an-unexpected-debut-aries-microgrid-infrastructure-powers-nrel-campus-through-outage.html
[7] https://www.tdworld.com/distributed-energy-resources/article/21131999/the-regulatory-path-forward-for-networked-microgrids

NREL considers these challenges opportunities for action, and continued investments in energy security and resilience will allow for innovation that hardens our grid against cyberattacks as well as disruptive weather.

Our researchers bring the unique expertise of renewable and increasingly distributed systems that are complex, autonomous, and built with greater resilience in mind. With our partners, we are looking at security solutions for future energy systems to expand situational awareness for highly distributed energy systems, dynamic power-communication systems emulation, cybersecurity standards and evaluation for distributed energy systems, and encryption technologies protecting the integrity of communication to and from new grid devices.

We're leading the development of the ARIES Cyber Range, which is powered by NREL's unique Cyber-Energy Emulation Platform (CEEP). With the ability to create entire energy systems in a virtual world, CEEP offers the safe exploration of cyber vulnerabilities and mitigation strategies—and it can support workforce development and training for growth in grid resilience and cyber defense jobs. CEEP is integrated with physical grid and cyber assets in the vast ARIES experimental platform to provide validation and ground truth in cyberattack scenarios.

But there is a lot more work to do. More investments will be needed for innovation, public-private cyber defense coordination, and workforce development focused on the security of future renewable and distributed energy systems.

We recognize a need to expand vulnerability assessments of future grid systems that can prioritize strategic innovation development. Within this space, NREL is leading a public-private partnership with the wind industry to coordinate and improve cyber defense for bulk power wind, but our vision is to bring this effort to every renewable energy sector. Current cybersecurity strategies applied to the bulk power systems will need to be improved or augmented if we're going to be successful in addressing the unique challenges we anticipate as the grid transforms to adopt more modern critical infrastructure.

The following offers a sample of additional projects and collaboration that highlight our efforts to enhance national energy security.

- ***Device-Level Security with Firmware Command and Control:*** As part of GMLC, NREL is collaborating with Argonne National Laboratory, Idaho National Laboratory, and Sandia National Laboratories to investigate the security of internal software in devices interacting with the grid. This project contributes to the state of the art in firmware research by gaining insight into embedded systems operations, evaluating operations through detection and remediation, response and detection based on machine-learning-firmware code behaviours, and connectivity to upstream data analytics.

- ***Blockchain for Optimized Security and Energy Management (BLOSEM):*** BLOSEM is a GMLC collaboration that aims to de-risk blockchain-based concepts through standardized metrics and cross-sector guidance. The team is exploring how blockchain can enable authentication of operating parameters for generation assets, secure communications for accessing and balancing demand response, secure market operations at the distribution level, and secure registration and authentication of distributed energy resources.

Situational Awareness of Grid Anomalies: With support from CESER, NREL is working with industry partner CableLabs on advanced electric grid data analytics and visualization for situational awareness of grid activity. The project is developing a method for cyber-physical anomaly detection so that early warning is possible for weather- or cyber-induced outages, safety violations, and economic disruption.

Resilience Planning and Recovery – Costs and Benefits, Technoeconomic Analysis

Rooted in disaster recovery, NREL researchers have learned first-hand what systems do and do not work during and after different disruptive events. We've developed replicable methodologies for assessing resilience postures and are developing quantifiable frameworks to model resilience metrics.

Understanding the nuances of power system vulnerabilities and how to finance resilience solutions has historically been a barrier for implementing resilient systems. Our research is working to overcome those barriers through robust energy modeling to further knowledge in this space. We build on our capabilities of visualizing, modeling, and developing tools to create a suite of resources for stakeholders to understand the greatest risks to their systems and operations and create a portfolio of mitigation and resilience solutions that apply to their specific context. These resources include the following:

- ***Proven Resilience Assessment Methodology:*** NREL researchers applied decades of lessons learned from disaster recovery technical assistance to develop a qualitative and quantitative approach to resilience assessments and planning. Historically, resilience assessment efforts external to NREL provide insight into where vulnerabilities exist but do not offer solutions. The methodology NREL developed establishes a baseline; identifies potential hazards, threats and vulnerabilities; and assigns scores to assess the highest risks. The methodology has been developed into a series of tools which also offer options to reduce the exposure or consequence of each potential vulnerability. Applying this methodology to grid systems can further enable resilience planning efforts.

  Resilience Planning – Costs and Benefits: An NREL-developed framework provides a methodology to determine the value of multiple resilience metrics (e.g., number of hours without power, potential business lost during an outage) over time and assign costs and values to those metrics. NREL has used this framework to provide site resilience assessments to partners and has incorporated it into the techno-economic analysis tool REopt, which is used for decision support in renewable energy projects. As we build the power system of the future and seek strategies for improving resilience, integrating the value of resilience into investment and operational decisions is critical. Though no one metric will cover all resilience planning needs, measuring the benefits of resilience investments, along with establishing valuation methodologies for such measures, will help enhance our ability to monetize investments associated with a more resilient electricity supply.[8]

- ***REopt:*** DOE's Federal Energy Management Program (FEMP) supported the development of REopt, a suite of tools that helps federal and private-sector decision makers make informed decisions about energy system investments. Developed to assess the technical, economic, and resilience benefits of energy investments, the REopt suite of tools is available as a free, online

[8] https://www.nrel.gov/docs/fy19osti/74673.pdf

tool, REopt Lite, and as open-source software for academia and the private-sector to improve upon.

- ***Technical Resilience Navigator:*** Another resource for energy system resilience planning is the Technical Resilience Navigator, developed for FEMP to identify risks and resilience opportunities for federal sites and their critical loads. The Technical Resilience Navigator leads users through resilience assessments that depend on site-specific load, risks, or other hazards, and proposes strategies to improve resilience.

Next Steps: Strengthening and Expanding Capabilities To Establish More Resilient Energy Systems

Our greatest capabilities to establish energy system resilience already exist: They are the combined national lab network, NREL's state-of-the-art ARIES research platform for integrated large-scale studies, and an engaged group of industry collaborators who are pushing the frontier of energy innovations.

Still, we've only just opened the door to many new research directions. Our capabilities are poised to reach even higher limits in designing and evaluating resilient systems. Unlike anything before, we are now able to study full-scale power systems in a controlled environment and look beyond to future energy scenarios.

Large-Scale Energy Transitions

Complementing the experimental scope of ARIES, we have the capacity to analyze energy systems and future scenarios in unprecedented detail, powered by high-performance computing and the combined simulation resources of multiple national labs. Through studies like the following, we can uncover the specific impacts of future market possibilities, or technological changes, and their effects on an energy system's resilience:

- ***The Los Angeles 100% Renewable Energy Study,*** or LA100, provides rigorous engineering-economic analysis of the Los Angeles energy system to support the city in its long-term planning.[9] Following the lead of LA100, large urban areas can answer essential questions about their integration options. As resilience is always the result of multiple factors, this level of detail and computational ability can express the principal components behind a community's resilience.

- ***Dallas-Fort Worth Airport:*** ARIES is also being used for a project in Texas to optimize the Dallas Fort-Worth airport's transportation and energy systems.[10] Along with more than a dozen collaborators, NREL is using ARIES to build a digital twin of the airport's energy system, including its complex transportation dynamics. Transportation hubs like DFW—one of the largest in the world—will continue to undergo energy transitions and understanding their investment options will be essential to maximize efficiency and resilience. NREL and national lab capabilities are now equipped to perform such integrated studies.

As mentioned, our resources for addressing "what-if" questions will be key for making informed progress. NAERM is our single most comprehensive capability to address national resilience, and there is

[9] https://www.nrel.gov/analysis/los-angeles-100-percent-renewable-study.html
[10] https://www.athena-mobility.org/

room to build this tool out further to capture deeper dynamics while becoming more functional for grid operators and planners. Our "what-if" resources can look ahead and deliver projections around electrification[11]or integrated mobility to reveal nationwide opportunities for energy security and resilience.

Summary of Key Takeaways and Research Needs for a Resilient Power System

- The February 2021 blackouts in Texas are another opportunity to explore how we can increase resilience of the U.S. electric infrastructure.
- A better understanding of extreme events and their impact on the complete power system, including interdependencies with other infrastructures, is necessary.
- DOE and the national lab complex have the capabilities and facilities to help the nation address its grid resilience challenges.
- DOE and the national laboratory system have significant simulation and analysis capabilities, such as the North American Energy Resilience Model, that can help understand the impacts of extreme events.

A variety of research needs should be investigated to help us prepare for transitioning to a future clean energy grid. These include:

- New methods to improve community preparation for, and response to, large-area, long-duration electricity interruptions, including through the use of energy efficiency, storage, and distributed generation technologies
- Technologies and capabilities to withstand and address the current and projected impact of the changing climate on energy sector infrastructure, including extreme weather events and other natural disasters
- Innovations to use distributed energy resources, such as solar photovoltaics, energy storage systems, electric vehicles, and microgrids, to improve grid and critical end-user resilience
- Advanced monitoring, analytics, operation, and controls of electric grid systems to improve electric grid resilience
- Analysis of technologies, methods, and concepts that can improve community resilience and survivability of frequent or long-duration power outages
- Advanced power flow control systems and components to improve electric grid resilience
- Methodologies to maintain cybersecurity at all times and especially during restoration of energy sector infrastructure and operation
- Consensus-based best practices to improve cybersecurity for distributed energy resources, including generation, storage, electric vehicles, and electric vehicle chargers
- A deeper exploration of resilience science to track resilience parameters of a system and provide the foundational principles to engineer more inherently resilient systems at a reasonable cost
- An integrated framework for cyber-resilience in the design and operation of autonomous energy grids, to include self-healing and self-optimizing communication networks; autonomous decision-making under adverse cyber events; and zero-trust architectures with new algorithms, methods, and tools.

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[11] https://www.nrel.gov/analysis/electrification-futures.html

I am appreciative of this opportunity to appear before the Subcommittee on a topic of vital national importance, and I look forward to answering any questions you may have.

Juan J. Torres

Associate Laboratory Director, Energy Systems Integration

National Renewable Energy Laboratory

Mr. Juan Torres is the Associate Laboratory Director for Energy Systems Integration at the National Renewable Energy Laboratory. In this role, he oversees NREL's research to modernize and strengthen the security, resilience and sustainability of the nation's electrical grid. Mr. Torres is Co-Chair for the Department of Energy's Grid Modernization Laboratory Consortium (GMLC), a partnership of 14 national laboratories to advance modernization of the U.S. power grid. In July 2019, Mr. Torres provided testimony to the Energy Subcommittee of the U.S. House of Representatives Committee on Science, Space, & Technology on modernizing and securing our nation's electricity grid. In 2018, Mr. Torres provided testimony to the U.S. Senate Energy and Natural Resources Committee on the topic of blackstart, the process of returning energy to the power grid after a system-wide blackout.

Prior to joining NREL in June 2017, Torres served in a variety of technical and management positions throughout his 27-year career at Sandia National Laboratories, most recently as deputy to Sandia's vice president for Energy and Climate programs. At Sandia, Mr. Torres led research efforts and vulnerability assessments in cybersecurity, guided research in advanced microgrid and renewable energy, and led the security and resilience team under the DOE's GMLC efforts. In 2004, Mr. Torres co-led the establishment of the DOE National SCADA Test Bed to secure power grid control systems from cyber attack. In 1998, Mr. Torres served as a member of the DOE task force that developed a national plan to secure the U.S. energy infrastructure in response to PDD-63 Critical Infrastructure Protection. From 1993-1995, Mr. Torres served as Sandia's engineering liaison to the Air Force Materiel Command at Peterson Air Force Base, CO, for development and deployment of mobile command and control systems in support of US Space Command and NORAD missions.

Mr. Torres holds a bachelor's degree in electronics engineering technology from the University of Southern Colorado, a master's degree in electrical engineering from the University of New Mexico, and has completed additional graduate work in Management Science and Engineering at Stanford University.

Chairwoman JOHNSON. Thank you very much, Mr. Torres.
Ms. Beth Garza.

TESTIMONY OF MS. BETH GARZA,

SENIOR FELLOW, R STREET INSTITUTE

Ms. GARZA. Thank you. Good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee. Before I get started, I want to add my recognition to the tremendous human impacts suffered by Texans during the February winter storms. I'm sure the efforts of this Committee will help ensure that the U.S. infrastructure—excuse me—becomes better able to withstand the challenges that it faces.

Today, I'm going to discuss three areas where research would be of most value. These are forecasting, the weatherization or winterization of power plants and their fuel supply, and the third area is the improved granularity of operation and control of demand within the electricity distribution systems.

So starting with forecasting, demand for electricity is very sensitive to weather conditions, primarily temperature, and as an industry, we've become very good at forecasting customer demand based on foreseeable weather conditions. However, if we had a better long-term view of potential weather conditions, system preparedness and resiliency would improve.

ERCOT prepares and publishes an assessment of demand and supply for each season. Unfortunately, their forecast for extreme demand this past winter was based on weather experienced during February 2011. The weather conditions actually experienced this year were much were much more severe. I believe all electric utility systems would benefit from new forecasting tools and techniques to ensure their longer-range planning is preparing them for the conditions that they may face.

Moving on to the winterization of supply, I caution that it's too early to draw detailed conclusions about the causes of all of the generator outages that we—that resulted in the curtailment of firm load, but based on preliminary data, it is clear that every type of generation—nuclear, coal, natural gas, wind, and solar—were limited in some manner during the extreme cold that we experienced.

Also, based on preliminary data, generator outages were primarily the result of insufficient weatherization and fuel supply disruptions. I've heard that maybe half of the outages that natural gas plants—power plants were due to the lack of fuel delivered at sufficient volumes and pressures. It's too early to draw specific conclusions other than to recognize the codependence of electricity and natural gas systems, especially in Texas.

Much has been made of the lack of mandatory winterization standards for power plants, and I suggest that it's easy to say that winterization should be mandatory, but effective regulations require a specific standard to be met, and any such standard should also have benefits that exceed cost. And one of the challenges power plants and natural gas system owners in Texas face is appropriately assessing the winterization benefits due to the relative infrequency of very cold weather. Winterization comes in various forms with different costs and performance implications, and understanding these costs and performance tradeoffs will be very valuable to the standard-setting process.

My last point has to do with distribution system improvements. Texas has an expansive advanced metering infrastructure. Preliminary results indicate that the Texas smart grid was not managed in a particularly smart manner. For example, the General Manager of Austin Energy, my local public power utility, described our advanced meters as capable of being disconnected remotely but requiring a person in the field to reconnect.

This same topic came up during a recent hearing at the Texas legislature where an executive from CenterPoint Energy, which serves the greater Houston area, described different limitations preventing them from using their advanced meters to manage curtailment. And limitations as I've heard them described seem to be a lack of supplemental technologies combined with institutional and policy differences. The same improvements that could have eased the burden of these lengthy outages to a subset of customers could also form the foundation for demand to express their willingness to pay and receive higher reliability. The ability to use scarce supply to serve demand, which values it the most, is the foundation of economic efficiency.

I look forward to your questions. Thank you.

[The prepared statement of Ms. Garza follows:]

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Testimony of Beth Garza

Senior Fellow, Energy

R Street Institute

Washington, D.C.

To the House Committee on Science, Space, and Technology

Hearing on "Lessons learned from the Texas blackouts: Research needs for a secure and resilient grid"

March 18, 2021

Chairwoman Johnson, Ranking Member Lucas and members of the committee:

Thank you for the opportunity to testify before you today on the critical topic of electric resilience in light of the power outages in Texas and other southern and midwestern states. My name is Beth Garza, and I am a senior fellow in the energy program at the R Street Institute, a pragmatic free-market think tank. Although the R Street Institute is a D.C.-based organization, I live in Austin, Texas and have held various roles in and around the Texas electricity market for more than 35 years, most notably serving as the Independent Market Monitor for the Electric Reliability Council of Texas (ERCOT) wholesale markets from 2014 through 2019. In this role, I was responsible for monitoring market participant activity, evaluating wholesale market operations and recommending improvements to the wholesale market design.

After providing a brief overview of the events in Texas during the week of Feb. 14, 2021, I offer three specific suggestions for areas of research that would be to improve the security and resiliency of the electricity system. My testimony concludes with a broader discussion of the policy implications and suggestions related to the Department of Energy.

Description of the February 2021 Power Outages

During the week of Feb. 14, 2021, an exceptional arctic air mass descended upon the middle of the country, including the entire state of Texas. This cold weather was extreme in both magnitude and duration. For example, in Austin a new record was set with 144 consecutive hours with below freezing temperatures. I can speak more authoritatively regarding the effects in the ERCOT region, but

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neighboring regions—the Southwest Power Pool (SPP), and the Midcontinent Independent System Operator (MISO)—also implemented emergency operations during the week.[1]

A common description of the ERCOT is that they are the folks that "run the grid". But what does that really mean? The ERCOT, similar to the other regional independent system operators, is the organization responsible for ensuring electricity supply equals demand at all times, and achieving that balance without allowing more electricity to flow on any transmission line than that line is designed to carry. The ERCOT does not own the generators, transmission lines or the demand. Most of the time this balancing act relies on supply going up and down in response to demand.

On Sunday, February 14, electricity demand reached a new winter peak that evening around 7:00 pm. Overnight demand levels did not decrease significantly, but supply became very limited. That is, power plants were unable to operate due to the effects of increasingly severe cold weather. By 1:20 early Monday morning, the amount of supply available was not sufficient to serve all demand and to maintain balance, and demand was curtailed.[2]

[1] Office of Cybersecurity, Energy Security, and Emergency Response, *Extreme Cold & Winter Weather | Update #1*, U.S. Department of Energy, Feb. 16, 2021. https://www.energy.gov/sites/prod/files/2021/02/f82/TLP-WHITE_DOE%20Situation%20Update_Cold%20%20Winter%20Weather_%231.pdf.

[2] Bill Magness, "Review of February 2021 Extreme Cold Weather Event," Electric Reliability Council of Texas, Feb. 24, 2021. http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISED_ERCOT_Presentation.pdf.

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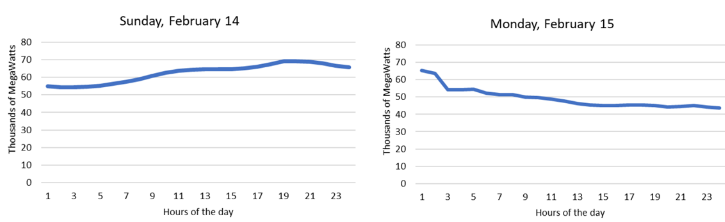

The ERCOT issued an order to the 17 distribution utilities in the region to interrupt the flow of electricity to enough of their customers to achieve the ERCOT-specified demand reduction target. These interruptions are accomplished by opening up a device located within a substation, which prevents the flow of electricity to an entire distribution circuit, or feeder. Based on my experience, the circuits selected for interruption typically serve several hundreds to a couple of thousand customers.

Under "typical" emergency conditions, these power interruptions are referred to as "rolling" outages because the idea is that no one set of customers should bear the entire curtailment burden, while keeping outage durations to specific customers limited in duration. As experienced in Texas this February, in many areas the amount of curtailment ordered meant all circuits not serving a critical load had to be shutoff; therefore sustained, not rolling outages ensued. I can speak to this from personal experience, as the electricity to my house was turned off for 81 consecutive hours. This was a common limitation felt by distribution utilities serving Austin and other urban areas. I assume this is due to higher concentrations of critical load in these areas.

Although there have been strong cries to find and assign the blame to someone, this event was larger and more impactful than any single person or entity could actually be responsible for. I suggest that there are many contributors and room for lots of improvement. To focus our attention today, I will discuss three key areas where research efforts would be of most value. These are 1) forecasting; 2) weatherization or winterization of power plants and their fuel supply; and 3) improved granularity of operation and control of demand within electricity distribution systems. I will conclude by offering my perspective on the policy implications for the federal government, specifically the Department of Energy.

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Weather and Demand Forecasting

Demand for electricity is very sensitive to weather conditions, primarily temperature. Electric utilities have become very good at forecasting customer demand based on foreseeable weather conditions. They are very accurate for the next day or two and based on a specific forecast of weather conditions, and are generally pretty accurate as much as seven to 10 days ahead. It would be valuable to have a better long-term view of potential weather conditions to improve electric system preparedness and assist with resiliency.

Weather expectations are also drivers for an increasing amount of supply, specifically forecasts of available wind and solar generation. Uncertainty in wind and solar generation forecasts were not a significant contributor to the recent February event. But accurately forecasting not just the expected output from these sources, but a reasonable range of outputs, becomes more important as wind and solar generation sources are an increasing portion of electricity supply.

The ERCOT prepares and publishes an assessment of demand and supply for each season. These assessments include both expected and potential extreme conditions.[3] Unfortunately, the ERCOT's forecast for extreme winter demand was based on weather experienced during February 2011. The weather conditions actually experienced during this past February were more severe, setting a new bar for what will be considered as extreme in the future. If weather events are getting more severe, I believe all electric utility systems would benefit from new forecasting tools and techniques to ensure their longer-range planning is preparing them for the conditions they may face.

Winterization of Supply

The ERCOT had what was believed to be an ample amount of installed generation capacity, but the massive reduction in available generation drove supply below firm demand, resulting in forced curtailments of customer demand. This is the final emergency action available to grid operators to maintain supply-demand balance and avoid a catastrophic systemwide blackout that could take weeks or longer to recover from. It is imperative to distinguish the causes of the supply shortfall relative to firm load, as well as how the shortfall was managed.

[3] "Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA) - Winter 2020/2021," Electric Reliability Council of Texas, Nov. 5, 2020. http://www.ercot.com/content/wcm/lists/197378/SARA-FinalWinter2020-2021.xlsx.

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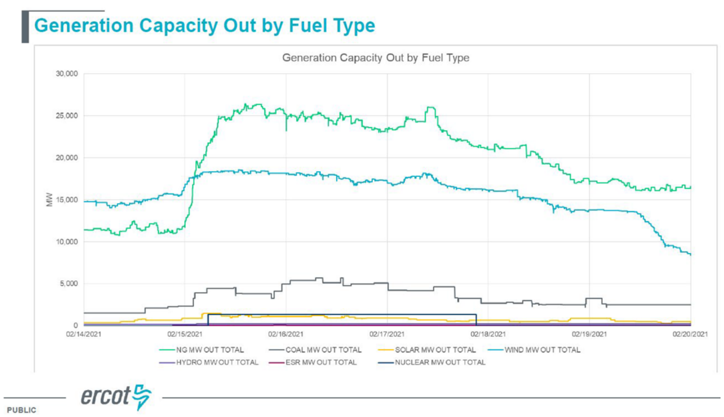
I caution that it is too early to draw firm, detailed conclusions about the causes of generator outages. Data about which power plants were not operating is just now becoming public.[4] Based on this data, testimony and public statements by generation owners, it is clear that every type of generation—nuclear, coal, gas, wind and solar—were limited in some manner during the extreme cold in ERCOT. Details about specific outage causes will take longer to develop and analyze. Still, we can provide a preliminary assessment based on currently available information, which indicates that the primary causes of generation outage were due to insufficient weatherization and fuel supply disruptions, especially for natural gas-fired facilities.



Non-verified statements have been made that maybe half of the outages at natural gas power plants were due to the lack of natural gas fuel delivered at sufficient volumes and pressures. It is too early to draw specific conclusions other than the co-dependence of the electricity and natural gas systems, especially in Texas, was once again centerstage.

Much has been made of the lack of mandatory winterization standards for power plants in Texas. I suggest that it is easy to say that winterization should be mandatory, but effective regulations require a

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[4] "Unit Outage Data," Electric Reliability Council of Texas, March 4, 2021. http://www.ercot.com/content/wcm/lists/226521/Unit_Outage_Data_20210304__Public_.xlsx.

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specific standard to be met. Should all Texas powerplants be required to be able to operate in subfreezing weather? For what duration? What about sub-zero temperatures?

Any such standards should also have benefits that exceed costs. One of the challenges power plant and natural gas system owners in Texas face in this regard is the relative infrequency of very cold weather, which limits and complicates the determination of winterization benefits. Power plant and natural gas fuel system winterization comes in various forms with different costs and performance implications. Understanding these cost and performance tradeoffs will be very valuable input to the standard-setting process.

Another value of improved forecasting of weather extremes would be its contribution toward establishing appropriate weatherization standards and requirements. Although we are focused today on the recent winter event in Texas, preparation for other types of extreme weather—heat, wind, rain—would be of value to all utilities across the country.

Distribution System Improvements

An overlooked takeaway from these events is that better deployment and utilization of advanced technologies could have reduced the magnitude of the supply shortfall and led to a less severe outcome. New "smart grid" technologies, when combined with market mechanisms, could have enabled a much deeper degree of voluntary demand reduction by end users that would have reduced the shortfall. To address any remaining shortfall, such technologies should enable the bulk system and distribution system operators an enhanced ability to stabilize power flows and enact more surgical involuntary curtailments based on the value of the end use activity. They can also enable the ability to restore power expeditiously to customers, ideally basing this priority according to the sensitivity of the end user to sustained power outages. Instead, some customers in the same municipal area never lost power while others lost it for days. Further, some critical uses like natural gas transport infrastructure were curtailed but some low value uses were not. What if there was the ability to ensure that non-critical uses of electricity (washing machines, dishwashers, etc.) were automatically limited, allowing scarce supply to be available for more important uses?

Texas, for example, has expansive advanced metering infrastructure (AMI) deployment but preliminary results indicate the Texas "smart grid" was not managed in a smart manner. For example, the general manager of Austin Energy, my local public power utility, described our "advanced" meters as capable of being disconnected remotely, but requiring a person in the field to reconnect. I heard this as I was sitting in my cold, dark house and thought, "here's an area for improvement." This same topic came up during hearings at the Texas Legislature, where an executive from CenterPoint Energy (serving the greater Houston area) described different limitations preventing them from using their advanced meters to

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manage the curtailments.[5] The limitations as I have heard them described, seem to be a lack of supplemental technologies combined with institutional and policy deficiencies.

The same improvements that could have eased the burden of lengthy outages on a subset of customers, could also form the foundation for demand (customers) to express their willingness to pay and receive higher reliability. The ability to use scarce supply to serve the demand which values it the most is the foundation of economic efficiency.

I have laid out three areas where technological improvements could improve grid resilience. But their success in doing so depends on evolving market conditions and regulatory architectures. Technology development institutions, like the Department of Energy (DOE), should be synchronized with the evolving energy regulatory contexts that vary across the state, regional and federal levels. For example, optimizing the DOE's assessments, coordination efforts and research and development (R&D) functions with the evolving functions and policy agendas of state public utility commissions and the Federal Energy Regulatory Commission (FERC) is crucial.

DOE Policy Implications

The translation of recent events into the proper role of government must identify tools suited to address legitimate market failures. Policy instrument choice must also account for the risk of government failure, whereby an intervention creates inefficiencies that can outweigh the harm caused by the market failure. In the case of the DOE's research agenda, market failure is most pronounced in knowledge spillovers, where the creation of knowledge by one entity can benefit others. Since an individual firm cannot capture these spillover benefits, this sometimes results in the private sector having insufficient incentive to develop and deploy new technologies.[6]

To maximize taxpayers' return on grid resilience R&D efforts, it is imperative that the DOE's innovation programs are routinely scrutinized and adjusted for changing conditions in the marketplace and regulatory environment. Last month's events serve as a case in point when there is a disconnect between technology development—such as the highly touted benefits of the "smart grid" in the 2000s—and the regulatory institutions that establish the rules of the road for technology deployment

[5] Texas House Joint Hearing of the State Affairs and Energy Resources Committees – Part 1, Feb. 25, 2021. https://tlchouse.granicus.com/MediaPlayer.php?view_id=46&clip_id=19369.
[6] Adam B. Jaffe, et al., "A tale of two market failures: Technology and environmental policy," *Ecological Economics*, Vol. 54 (2-3), August 2005. http://www.sciencedirect.com/science/article/pii/S0921800905000303.

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and management. This should not come as a surprise, as a report last year from the DOE's Advanced Grid Research division found that AMI deployment was costly nationwide with speculative but "wide-ranging benefits that are highly dependent on how the technology is implemented and the value streams pursued." [7] Value streams for grid resilience are exceptionally dependent on the regulatory architecture. With this backdrop, last month provides another reminder of a critical lesson for the DOE and regulatory bodies: coordinate agendas to maximize the net benefits of emergent grid resilience technologies.

In recent years, the DOE has increased its interagency coordination with the FERC and the North American Electric Reliability Corporation (NERC) on matters of grid resilience and security.[8] Synchronizing FERC rules and NERC reliability guidance and standards alongside DOE activities should guide technological development. But it also highlights the value of the DOE's other functions, namely in developing and disseminating information and coordinating government and private sector activities.

Last month's events should inform an adjustment to the DOE, the FERC and the NERC's joint agenda. Previous evidence on grid resilience heavily emphasized transmission and distribution as the most vulnerable components, while fuel limitations were a minor factor in generation susceptibility. Last month's events, however, indicated the vulnerability of power generation to a single type of event, and likely will put added emphasis on addressing power plant fuel assurance, especially as it relates to the interdependency with natural gas infrastructure. Deploying the DOE's enhanced natural gas-electric system modeling could greatly inform next steps for the FERC and the NERC in their response. However, the most important lesson is that regardless of the cause of the supply shortfall, massive improvement in regulatory and technology development spheres is needed to improve demand-side responsiveness.

Specific DOE policy recommendations include:

1. *Orient DOE strategies to enable programmatic flexibility and robustness in the face of uncertainty*. Market conditions, regulatory environments and technologies are dynamic. The DOE's strategic orientation should preserve option value in programmatic adjustments to avoid inefficient "lock-ins" but also recognize the downsides of constant tinkering in R&D programs,

[7] Advanced Grid Research, *AMI in Review: Informing the* Conversation, U.S. Department of Energy, last accessed March 15, 2021, p. 48. https://www.smartgrid.gov/documents/voe_series/voe-ami-in-review-informing-the-conversation.

[8] See e.g., "Statement of James B. Robb," Docket No. AD19-12-000, North American Electric Reliability Corporation, March 28, 2019. https://www.nerc.com/news/testimony/Testimony%20and%20Speeches/FERC%20Security%20Incentives%20Technical%20Conference%203-28-19%20FINAL.dotx.pdf.

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whose productivity is very sensitive to long-term programmatic stability. R&D programs designed to deploy resources in a manner to maximize net benefits across a broad set of future scenarios will age well and put taxpayer dollars to better use.

2. *Target DOE assessments, technology development pathways and interagency collaboration toward identifying and rectifying common mode failure*. Such efforts should reflect and build upon existing research, especially that which identifies correlated outages of extended durations. Currently, many industry-planning methods presume generation outages are independent, or uncorrelated, with one another. This can result in planning methods that understate the probability of supply disruptions, including those tied to common mode events like severe weather, cyber and physical attacks, and natural gas supply constraints.[9] The increasing share of natural gas and renewables generation, which exhibit extensive correlated derates and outages, underscores this value.
3. *Bolster demand responsiveness to any cause of supply disruption*. Although the specific causes of February's outages could be rectified, I caution against presuming that avoiding this type of event altogether is achievable. A risk of mass disruptions to bulk electric supply will always exist, be they from extreme weather, natural disasters or intentional attacks. Thus, we must focus on the ability to manage scarce resources and the ability to "bounce back" from grid emergencies. Technologies enabling us to do so include advanced sensors, monitors and flow controls, all which enable more voluntary demand reduction and, when necessary, more surgical involuntary load curtailments. This customer-centric approach requires advanced technology to expand the ability of consumers to receive a level of service reliability that they are willing to pay for in the competitive marketplace.
4. *Focus on the resilience of the natural gas system, especially at its nexus with the electricity system*. Enhanced DOE assessments of natural gas-electric system interdependencies could greatly inform state and federal rulemakings, prudency reviews and standards development, in addition to informing market participants and legislators. Market forces should dictate the role natural gas plays in our energy future, whereas policies to advance technologies can help private sector-led investment mitigate the risks of gas supply chain disruptions and bolster its ability to bounce back.
5. *Align energy R&D spending with spillover benefits across federal and state regulatory contexts*. The most prudent R&D spending is upstream in the innovation cycle, where spillover benefits are greatest. These should be accompanied by DOE program performance metrics, regular program reevaluation to determine when to phase-out public investment, and stronger linkages

[9] *Exploring the Impacts of Extreme Events, Natural Gas Fuel and Other Contingencies on Resource Adequacy*, Electric Power Research Institute, Jan. 28, 2021. https://www.epri.com/research/products/000000003002019300.

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to private sector needs across differing electric regulatory model.[10] DOE advisory processes and technology assessments should reflect the commercial usefulness of such technologies in all relevant regulatory contexts, such as soliciting input from power generators and state regulators under both the regulated monopoly utility model and competitive independent power producer model. All expenditures should be scrutinized in context of a highly constrained fiscal environment.[11]

Although I cannot comment on all aspects of the Grid Security Research and Development Act (H.R. 5760), I am encouraged by the role of the DOE to 1) administer *competitive* grants tied to enhancing energy sector resilience and emergency response; 2) collaborate strategically with other federal and state agencies and the private sector and; 3) implement an R&D program to help address tomorrow's energy sector resilience and security concerns.

I look forward to your questions.

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[10] See e.g., "Testimony of Devin C. Hartman before the U.S. House Committee on Energy and Commerce Subcommittee on Energy Hearing on 'Federal Energy Related Tax Policy and its Effects on Markets, Prices and Consumers'," March 29, 2017, p. 15. https://docs.house.gov/meetings/IF/IF03/20170329/105798/HHRG-115-IF03-Wstate-HartmanD-20170329.pdf.

[11] *Ibid*.

Beth Garza is a senior fellow with R Street's Energy & Environmental Policy Team.

Prior to joining R Street, Beth served as the director of the Electric Reliability Council of Texas Independent Market Monitor from 2014 through 2019 after serving as the deputy director since 2008. In this role, she was responsible for monitoring market participant activity, evaluating wholesale market operations and recommending improvements to the wholesale market design.

Over the course of her 35-year career in the electric utility industry, Beth has held a variety of leadership roles in generation and transmission planning, system operations, regulatory affairs and market design for both regulated and competitive entities. Her previous employers include Nextera and Austin Energy.

Beth is a graduate of the University of Missouri and is a registered professional engineer in the State of Texas.

Chairwoman JOHNSON. Thank you very much, Ms. Garza.
Dr. Sue Tierney.

TESTIMONY OF DR. SUE TIERNEY, SENIOR ADVISOR, ANALYSIS GROUP

Dr. TIERNEY. Good morning, Chairman—Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee. My name is Sue Tierney. Although I am testifying today on my own behalf, I also share various grid resiliency and research-related recommendations from two recent National Academies of Sciences Committees on which I have served.

The recent power outages in Texas led to extremely challenging living conditions for millions of people and of course the tragedy of 70 people having lost their lives. It disrupted access to critical services like heating and water supply. This crisis highlights the critical role that reliable and resilient electric service plays in the health and well-being of Americans.

It is clear that steps could have been taken by State officials, grid operators, and energy companies in Texas that would have lessened the extent of the crisis in these human hardships. These events cry out for the need for further research to ensure a resilient electric supply, especially as we anticipate worsening and more frequent extreme weather conditions in the decades ahead.

The Federal Government has an essential role to play here. As the Academies of Sciences' 2017 report on enhancing the resiliency of the electric grid pointed out—and I'm quoting here—"The Department of Energy is the Federal entity with a mission to focus on the longer-term issues of developing and promulgating technologies and strategies to increase the resilience and modernization of the grid." No other entity in the United States has the mission to support such work. This is a public good. If funding were not provided by the Federal Government, this gap in research won't be filled by the States or the private sector. In short, this is a role for the Federal Government.

In my written testimony, I discussed factors that affected the power outages in Texas and related research needs. Because others on the panel have already talked about the Texas electricity crisis, I would only add a couple of points. Texas is the only State in the United States with an electric industry structure that combines an energy-only competitive wholesale market and mandatory customer choice among competitive retail suppliers. This is largely viewed by academic economists as having been a successful electricity market design, although some observers, including myself, have questioned whether such an approach that relies explicitly on the expectation of very high electricity prices, at times power shortages, is politically sustainable in the event that such conditions actually occur.

Now, for several years the North American Electric Reliability Council (NERC) pointed—has pointed out ERCOT's slim reserve margins as contributing to reliability risks. Texas previously experienced winter conditions which created electric reliability problems. In following up on investigations in 2011, the staff of the Federal Energy Research—Regulatory—excuse me, Regulatory Commission (FERC) and NERC said the outages could have been avoided, and they encouraged State policymakers to adopt policies to encourage performance of the system under stressful conditions. However, for the most part, policymakers and the electric and gas industries in Texas did not act on these recommendations, and this set the stage for the events in February this year. Clearly, these are a chilling reminder of the critical need for reliable and resilient electricity in the—our basic needs.

Although the Texas electricity crisis was an unusual event, it could happen anywhere, and proactive steps should be taken to lower the risk impacts of the occurrences. The 2017 Reliability and Resilience Report from the National Academies, along with a new report in February 2021 on the future of the power system, identified grid resilience as a key issue. In my written testimony, I have provided seven pages of findings and recommendations from these two studies, and I won't go through them here. Let me just mention a very short set.

First, we conclude that research—scientific research and applied development and demonstration programs related to the electric industry should be tripled. That's for science, and much more of this support should be in multiyear appropriations.

I see my time is up, and I would encourage the Committee to take a careful look at my written testimony for the additional recommendations. And I appreciate so much the Committee's attention to these important issues. Thank you.

[The prepared statement of Dr. Tierney follows:]

Testimony of Susan F. Tierney, Ph.D.
Senior Advisor
Analysis Group, Inc.
Denver, Colorado

Before the U.S. House
Committee on Science, Space and Technology

Committee Hearing on
"Lessons learned from the Texas blackouts: Research needs for a secure and resilient grid"
March 18, 2021

Testimony

Introduction

Good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee.

My name is Susan Tierney.[1] I am a Senior Advisor at Analysis Group, an economic consulting firm where I specialize on policy, regulation, economics, environmental, and innovation issues associated with the electric and gas industries.

Thank you for inviting me to testify at this important hearing aimed at discovering what caused the recent extended power outages in Texas during a severe winter storm in mid-February of 2021, and identifying critical research and development needs for grid resilience, reliability and security. I understand that you are particularly interested in research sponsored by the Department of Energy related to relevant grid technology, energy generation technology and cybersecurity research.

I further understand that this hearing serves as a legislative hearing for a bill — Grid Security Research and Development Act (H.R. 5760 in the 116th Congress), which was previously introduced by Representative Ami Bera — expected to be reintroduced in this Congress. That bill would authorize an interagency research, development, and demonstration program on electric-grid and energy-system cybersecurity, physical security, resilience, and emergency response.

I am testifying on my own behalf at today's hearing and it is an honor to share my thoughts and observations with you. But as part of my testimony, I will also share various research-related recommendations of several recent committees of the National Academies of Sciences, Engineering and Medicine ("The Academies") on which I have recently (or currently) served.[2] The recommendations from those committees' reports that I describe in this testimony are ones that relate to resilience, grid modernization and planning, and cyber security. I will be careful to identify those instances where I am reporting the consensus results of those committees versus expressing my own opinion. All of the

[1] I have provided my bio at the end of this testimony.
[2] These three Academies committees on which I have served and whose recommendations I discuss in this testimony are:
- Enhancing the Resilience of the Nation's Electric System (2017), https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system.
- The Future of Electric Power in the U.S. (2021), https://www.nationalacademies.org/our-work/the-future-of-electric-power-in-the-us;
- Accelerating the Decarbonization in the United States: Technology, Policy and Societal Dimensions (2021). https://www.nationalacademies.org/our-work/accelerating-decarbonization-in-the-united-states-technology-policy-and-societal-dimensions.

National Academies' reports from which I will draw recommendations were completed prior to the Texas events that have prompted this hearing.

The February 2021 outages in Texas led to extremely challenging living conditions for households, including long periods without power and in some cases also without access to other critical services (like water supply) in parts of the state. In holding this hearing, the Science Committee is examining important issues: What led to these events? And what research is needed to avoid or at least minimize the impacts of such events in the future?

The February 2021 Texas electricity crisis highlights the extraordinarily important role that reliable and resilient electric service plays in the economic and social health and well-being of American communities.

It is clear that steps could have been taken by state officials, grid operators and energy asset owners in Texas that would have at least lessened the extent of power system and gas system outages, and the human hardships that resulted from them.

The events also cry out for the need for further research and analysis (not to mention policy and system changes) to ensure reliable and resilient electric supply in the future, even in the event of extreme weather conditions that we can anticipate in the decades ahead. The federal government has an essential role to play in supporting this research. As the Academies' 2017 report on Enhancing the Resilience of the Electric Grid pointed out:

> The Department of Energy (DOE) is the federal entity with a mission to focus on the *longer-term* issues of developing and promulgating technologies and strategies to increase the resilience and modernization of the electric grid. No other entity in the United States has the mission to support such work, which is critical as the electricity system goes through the transformational changes described in this report. The committee views research, development, and demonstration activities that support reliable and resilient electricity systems to constitute a public good. If funding is not provided by the federal government, the committee is concerned that this gap would not be filled either by states or by the private sector. In part this is because the challenges and solutions to ensuring grid resilience are complex, span state and even national boundaries, and occur on time scales that do not align with business models.[3]

I appreciate the Science Committee's attention to these important research questions.

In my testimony, I first discuss the factors that affected the electricity outages that occurred in parts of Texas for several days in February 2021. In this part of my testimony, I draw upon my own experience and understanding of what transpired there. When I turn to the second part of my testimony—where I discuss related research needs for a robust, reliable, safe, and resilient electric system—I draw more directly on the work of the National Academies' committees on which I served.

Factors affecting the electric supply outages in Texas in February 2021:

Much has already been written and said about the Texas electricity crisis, the related public health and safety concerns (and tragedies), and exorbitant electricity price increases in the portion of Texas where the Electric Reliability Council of Texas ("ERCOT) manages the grid and wholesale power market.

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[3] National Academies of Sciences, Engineering, and Medicine, *Enhancing the Resilience of the Nation's Electricity System*, 2017 (hereafter referred to as "Academies' 2017 Resiliency Report"), at https://doi.org/10.17226/24836.

There have already been numerous federal and state legislative and regulatory hearings;[4] bills introduced in Congress[5]; lawsuits;[6] and investigations.[7] Experts are weighing in to explain these events in seminars[8] and podcasts[9], in magazine,[10] newspaper[11] and industry articles,[12] and in other many other commentaries.[13]

Given the extensive coverage of the 2021 Texas electricity crisis, I will just briefly summarize here some of the important pre-existing conditions in the ERCOT electric system, key developments that occurred

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[4] For example: Senate Energy and Natural Resources, Full Committee Hearing on Reliability, Resiliency, And Affordability of Electric Service, March 11, 2021, at https://www.energy.senate.gov/hearings/2021/3/full-committee-hearing-on-the-reliability-resiliency-and-affordability-of-electric-service; Texas Legislature - Joint Hearing of State Affairs and Energy Resources Committees, February 25, 2021, at https://www.youtube.com/watch?v=bmFkAdEAcS0.

[5] See: the Disaster Safe Power Grid Act, sponsored by Senators Wyden and Merkley, at https://www.wyden.senate.gov/imo/media/doc/Disaster%20Safe%20Power%20Grid%20Act%20of%202021%20Bill%20Text.pdf.

[6] Examples: CPS Energy v. ERCOT, March 12, 2021, as described in Brendon Gibbons, "CPS Energy sues ERCOT, alleging 'one of the largest illegal wealth transfers in the history of Texas,'" San Antonio Report, March 12, 2021, at https://sanantonioreport.org/cps-energy-sues-ercot/; The State of Texas v. Griddy Energy LLC and Griddy Holdings LLC, https://www.texasattorneygeneral.gov/sites/default/files/images/admin/2021/Press/01_Griddy%20Petition_2.28.21%20file%20stamped.pdf, as described in Attorney General Kenneth Paxton press release, March 1, 2021, at https://www.texasattorneygeneral.gov/news/releases/ag-paxton-sues-griddy-llc-energy-company-customers-hit-exorbitant-energy-bills.

[7] For example: Federal Energy Regulatory Commission News Release, "FERC, NERC to Open Joint Inquiry into 2021 Cold Weather Grid Operations," February 16, 2021, at https://www.ferc.gov/news-events/news/ferc-nerc-open-joint-inquiry-2021-cold-weather-grid-operations; FERC News Release, "FERC to Examine Potential Wrongdoing in Markets During Recent Cold Snap," February 22, 2021, at https://www.ferc.gov/news-events/news/ferc-examine-potential-wrongdoing-markets-during-recent-cold-snap; Garrett Hering, "In the wake of the storm, Texas PUC opens probe into outages," S&P Global Market Intelligence, February 19, 2021, at https://platform.marketintelligence.spglobal.com/web/client?auth=inherit&overridecdc=1&#news/article?KeyProductLinkType=2&id=62768135.

[8] For example: International Association of Energy Economists; Keystone Energy Board.

[9] For example: Columbia University Center for Global Energy Policy ("Making Sense of the Texas Energy Crisis," February 22, 2021, at https://www.energypolicy.columbia.edu/making-sense-texas-energy-crisis); RFF Resources Radio ("Shedding Light on Electricity Blackouts, with Severin Bornstein," February 23, 2021, at https://www.resources.org/resources-radio/shedding-light-on-electricity-blackouts-with-severin-borenstein/); RFF Resources Radio ("Illuminating the Future of Electric Power in the United States, with Karen Palmer," March 9, 2021, https://www.resources.org/resources-radio/illuminating-the-future-of-electric-power-in-the-united-states-with-karen-palmer)/; Volts (David Roberts, "Lessons from the Texas mess," February 23, 2021, at https://www.volts.wtf/p/lessons-from-the-texas-mess).

[10] For example: Robinson Meyer, "Texas Failed Because It Did Not Plan," *The Atlantic*, February 21, 2021, at https://www.theatlantic.com/technology/archive/2021/02/what-went-wrong-texas/618104/?utm_source=newsletter&utm_medium=email&utm_campaign=atlantic-weekly-newsletter&utm_content=20210221&silverid-ref=MzEwMTkwMjQxOTU4S0.

[11] For example: Katherine Blunt and Russell Gold, "The Texas Freeze: Why the Power Grid Failed," *The Wall Street Journal*, February 19, 2021, at https://www.wsj.com/articles/texas-freeze-power-grid-failure-electricity-market-incentives-11613777856; Russell Gold and Katherine Blunt, "Texas Grapples with Crushing Power Bills After Freeze," *The Wall Street Journal*, February 23, 2021, at https://www.wsj.com/articles/texas-grapples-with-crushing-power-bills-after-freeze-11614095953; Russell Gold and Katherine Blunt, "Amid Blackouts, Texas Scrapped Its Power Market and Raised Prices. It Didn't Work," *The Wall Street Journal*, February 25, 2021, at https://www.wsj.com/articles/texas-power-regulators-decision-to-raise-prices-in-freeze-generates-criticism-11614268158.

[12] For example: Alex Gilbert and Morgan Bazillian, "The Texas electricity crisis and the energy transition," *Utility Dive*, February 19, 2021, at https://www.utilitydive.com/news/the-texas-electricity-crisis-and-the-energy-transition/595315; Molly Christian, Zack Hale and Ellie Potter, "Experts mull market, reliability rule changes amid Texas, regional outages," *S&P Global Market Intelligence*, February 16, 2021, at https://platform.marketintelligence.spglobal.com/web/client?auth=inherit&overridecdc=1&#news/article?KeyProductLinkType=2&id=62688009; Edward Klump, "Texas Blackouts: 10 ways to fix the grid," E&E News, at https://www.eenews.net/stories/1063727199.

[13] For example: Jay Apt and Luke Lavin, "Opinion: What is happening in Texas will keep happening until we take action," *Washington Post*, February 18, 2021, at https://www.washingtonpost.com/opinions/2021/02/18/texas-power-grid-failure-weather/; Carl Pechman and Elliott Nethercutt, "Regulatory Questions Engendered by the Texas Energy Crisis of 2021," NRRI Insights, March 2021, at https://pubs.naruc.org/pub/2AF1F2F3-155D-0A36-3107-99FCBC9A701C; Peter Cramton, "Ten myths of the 2021 Texas electricity crisis and ten steps to avoid a repeat," March 8, 2021.

in tandem as part of the electric crisis, and some of the key conditions and impacts associated with the electrical outages in the ERCOT Texas region.

Pre-existing conditions before the mid-February events

- The ERCOT electric system is one of the largest integrated electric grids around the world, even though it is electrically separated from the rest of the power systems in the lower 48 states in the U.S. From a physical point of view, the ERCOT system includes vast networks of high-voltage transmission lines and a diverse set of power plants (including nuclear, coal, natural gas, and renewable facilities). Sales of electricity to Texas consumers account for 11 percent of the nation's total retail sales.[14]

- For nearly two decades, electricity supply to consumers in the ERCOT portion of Texas has been supplied through restructured, competitive wholesale and retail electricity markets. ERCOT administers the wholesale power market, with oversight by the Public Utility Commission of Texas ("PUCT"). (The Federal Energy Regulatory Commission ("FERC") does not have jurisdiction over wholesale sales in ERCOT because there are no sales in interstate commerce, in light of ERCOT being electricity isolated from other states.) The PUCT has approved a market design for ERCOT's system market that includes the "gold standard" — an approach called a "bid-based, security-constrained economic dispatch with locational marginal pricing" — for determining the pricing and efficient dispatch of electricity resources on the system. Unlike every other region in the U.S. with a centralized grid operator like ERCOT, however, Texas has neither a mandatory centralized capacity market administered by the grid operator (as in the 13-state PJM region, or in New York or New England) nor a state-supervised least-cost resource planning process (as in California, and in the states that participate in the MISO and SPP regions in the central part of the U.S.) in order to ensure that adequate supplies of electrical resources exist on the system. The PUCT has approved this "energy-only market" approach for the ERCOT region, relying on the role of price spikes during periods of electricity shortages to create incentives for investment so that generating resources are available to produce power during those periods.

- The PUCT also oversees the retail electricity market in the service territories of investor-owned utilities. In the ERCOT portion of Texas (i.e., in most of Texas), each electricity customer must choose his/her preferred competitive retail supplier (called Retail Electricity Providers), with power delivered over wires owned by electric utilities).[15] Retail Electricity Providers offer a variety of types of service and price options to customers, including ones with fixed prices over a pre-established contract period and others with prices that vary according to prices that change in the hourly wholesale markets.

- Texas is the only state with this particular combination of elements in its electric industry: a restructured, energy-only wholesale market; and mandatory consumer choice of competitive power suppliers. Largely viewed by academic economists and many—but not all—industry experts as a

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[14] Data for 2019 from U.S. Energy Information Administration, State Electricity Profiles, https://www.eia.gov/electricity/state/.

[15] Although retail choice is mandatory for electricity customers of investor-owned utilities, it is only available to customers of municipal and cooperative utilities if the utility opts-in, something that has rarely occurred. https://www.puc.texas.gov/consumer/facts/faq/Muni.aspx; https://quickelectricity.com/electricity-choice-in-texas-why-dont-all-texans-have-choice-in-electric-providers/.

successful electric market design, in terms of producing economically efficient outcomes. (I note that some industry observers, including myself, have questioned whether such a market design, which relies explicitly on the expectation of price spikes at times of power shortages is politically sustainable in the event that such conditions actually occur.[16])

- For several years, the North American Electric Reliability Corporation ("NERC") has pointed to the fact that ERCOT operates with slim reserve margins and with related potential reliability risks. As explained by James Robb, who leads NERC, in March 11th, 2021 testimony before the Senate Energy and Natural Resources Committee: "Concern for ERCOT's reserve margins has been a standing concern in NERC's assessments. In the most recent 2020/2021 Winter Reliability Assessment, NERC warns of the potential for extreme generation resource outages in ERCOT due to severe weather in winter and summer, and the potential need for grid operators to employ operating mitigations or energy emergency alerts to meet peak demand."[17]

- Although Texas is typically a summer-peaking system, with highest electrical demand during the hottest-weather months, it has previously experienced extreme cold weather conditions during the winter which created electric reliability problems when power plants were not able to perform, for one reason or another. During a cold snap that affected the Southwestern states (including Texas) in February 2011, for example: "Between February 1 and February 4, a total of 210 individual generating units within the footprint of [ERCOT] … experienced either an outage, a derate, or a failure to start. The loss of generation was severe enough on February 2 to trigger a controlled load shed of 4000 MW, which affected some 3.2 million customers."[18] ERCOT had thus experienced prior difficulties in maintaining reliable electricity service during extreme winter weather conditions.

- Following an investigation of that February 2011 cold-weather reliability event in the Southwest, the staffs of FERC and NERC made findings and recommendations that were relevant to actions of state legislators and regulators, owners of electric generating units, and parties in the natural gas industry in Texas.[19] The FERC/NERC report encouraged, among other things, that state policy

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[16] "Although many economic experts in the electric industry point to the success of the ERCOT market design as a model that should be adopted and implemented in other regions, it is unlikely that that approach—with its mandatory retail competition and an energy-only centralized wholesale market—will be taken up in most (if any) other regions of the U.S." Susan Tierney, "Wholesale Power Market Design in a Future Low-Carbon Electric System: A Proposal for Consideration," November 28, 2020, at https://media.rff.org/documents/tierney-white-paper-on-wholesale-market-design-12-15-2020-final-to-wri-rff.pdf. Also, "Exporting the ERCOT model? It would surprise me if any other states can or choose to pursue it, even if it has been successful there. (And the jury is out about how well it would work with it is dominated by zero-emitting resources, rather than 64% fossil.)" Susan Tierney, "Wholesale Power Market Design in a Future Low-Carbon Electric System: A Proposal for Consideration," World Resources Institute/Resources for the Future Workshop on market designs for the clean energy transition, December 17, 2020, at https://media.rff.org/documents/tierney-wri-rff-market-design-workshop_-_12-17-2020_v2.pdf.

[17] James Robb, President and CEO of NERC, "Reliability, Resiliency, and Affordability of Electric Service in the United States Amid the Changing Energy Mix and Extreme Weather Events," testimony before the Senate Energy and Natural Resources Committee, March 11, 2021, at https://www.energy.senate.gov/services/files/EB1D7E02-BC93-4DFF-A6A9-002341DA34CF.

[18] Staffs of the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation, "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations" (hereafter referred to as the "FERC/NERC Staff Report on 2011 Cold Weather Events"), https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf.

[19] FERC/NERC Staff Report on 2011 Cold Weather Events.

makers adopt policies to encourage actions to ensure improved performance of power systems. These findings and recommendations included the following:

- Finding: "The lack of any state, regional or Reliability Standards that directly require generators to perform winterization left winter-readiness dependent on plant or corporate choices…."[20]
- Finding: "Generators were generally reactive as opposed to being proactive in their approach to winterization and preparedness. The single largest problem during the cold weather event was the freezing of instrumentation and equipment."[21]
- Recommendation: "Transmission Operators and Balancing Authorities should obtain from Generator Owner/Operators their forecasts of real output capability in advance of an anticipated severe weather event; the forecasts should take into account both the temperature beyond which the availability of the generating unit cannot be assumed, and the potential for natural gas curtailments."[22]
- Recommendation: "States in the Southwest should examine whether Generator/Operators ought to be required to submit winterization plans, and should consider enacting legislation where necessary and appropriate."[23]
- Recommendation: "Lawmakers in Texas and New Mexico, working with their state regulators and all sectors of the natural gas industry, should determine whether production shortages during extreme cold weather events can be effectively and economically mitigated through the adoption of minimum, uniform standards for the winterization of natural gas production and processing facilities."[24]

- In their release of the 2011 report, the FERC and NERC staffs said that the outages could have been avoided, and "that the purpose of the report was not to assign blame but to look at the causes of the outages and figure out the best ways to prevent them in the future."[25]
- For the most part, the electric industry and gas industry in Texas did not act on these recommendations, nor did regulators at the PUCT (for electric industry issues) or at the Texas Railroad Commission (for gas industry issues). As of the start of 2021, the power generation and gas production/delivery systems in Texas had not undergone the types of weatherization actions that could have enabled the provision of energy supply in the event of extreme winter temperature events.[26] Apparently, the owners of these power-generation and natural gas facilities were not

[20] FERC/NERC Staff Report on 2011 Cold Weather Events, page 196.
[21] FERC/NERC Staff Report on 2011 Cold Weather Events, page 196.
[22] FERC/NERC Staff Report on 2011 Cold Weather Events, page 202.
[23] FERC/NERC Staff Report on 2011 Cold Weather Events, page 203.
[24] FERC/NERC Staff Report on 2011 Cold Weather Events, page 214.
[25] J.P. Finlay, "FERC/NERC report outlines steps to avoid winter outages in Southwest," *S&P Global Market Intelligence, August 16, 2011, at* https://platform.marketintelligence.spglobal.com/web/client?auth=inherit&overridecdc=1&#news/article?KeyProductLinkType=2&id=13185142
[26] Molly Christian, Zack Hale and Ellie Potter, "Experts mull market, reliability rule changes amid Texas, regional outages," *S&P Global Market Intelligence*, February 16, 2021, at https://platform.marketintelligence.spglobal.com/web/client?auth=inherit&overridecdc=1&#news/article?KeyProductLinkType=2&id=62688009.

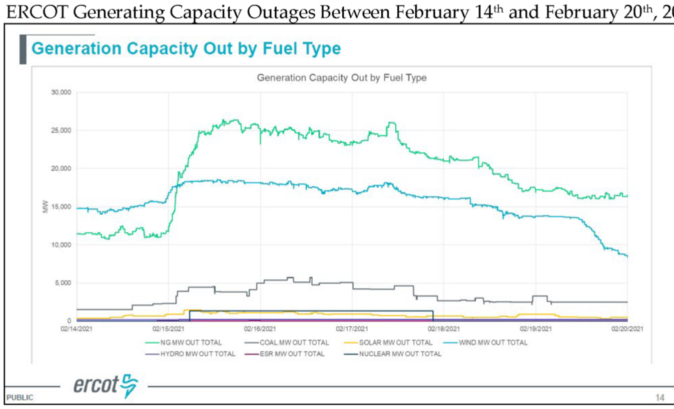
sufficiently incented by ERCOT Texas' market design to voluntarily put in place the physical equipment and/or contract agreements to enable them to be available to operate during shortage conditions.

- These—and other—conditions set the stage for the energy emergency events in February 2021.

What Happened: Real-time contributors to the Texas power outages

- During the second week of February 2021, extreme winter weather conditions affected the middle of the country, with frigid temperatures, snow and ice lasting for days. While other parts of that region routinely expect harsh conditions in the winter, Texas was particularly hard hit. Although ERCOT expected cold weather, the conditions were more extreme than anticipated.[27]
- In the ERCOT region, this weather produced record-breaking winter-time demand for electricity at the same time that various adverse conditions developed on the supply side.[28] From an electric-generating capacity point of view, power plant equipment froze, with over 48% of the region's total capacity unavailable at the highest point in the outages. All types of generating technologies experienced outages, with gas-fired capacity experiencing the highest amount of shut-down equipment (as shown in the ERCOT chart (Figure 1), below).

Figure 1:
ERCOT Generating Capacity Outages Between February 14th and February 20th, 2021[29]



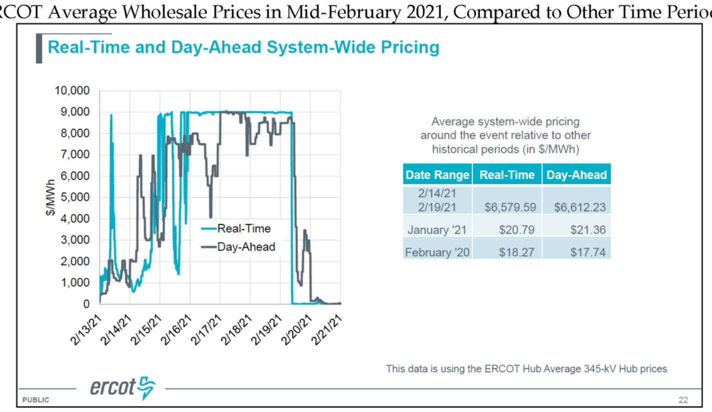
- From a fuel-supply point of view, natural gas became unavailable to significant numbers of power plants in ERCOT as gas wellheads and processing facilities froze up and as gas supply was

[27] ERCOT press release, "Extreme cold weather expected to result in record electric use in ERCOT region," February 11, 2021, at http://www.ercot.com/news/releases/show/224996.
[28] Bill Magness, "Review of February 2021 Extreme Cold Weather Event," ERCOT Presentation to Urgent ERCOT Board of Directors Meeting ERCOT, February 24, 2021 (hereafter "ERCOT 2-24-201 Presentation"), at http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISED_ERCOT_Presentation.pdf.
[29] ERCOT 2-24-201 Presentation.

prioritized for home heating.[30] This led to price spikes in natural gas markets, with prices skyrocketing at points to 100 times their normal levels.[31]

- To avoid a catastrophic system-wide outage as potential demand exceeded available generation, ERCOT instituted rolling blackouts ("load shedding") to lower demand and move it to levels that could be met by generation. Such involuntary curtailments of electricity service extended over nearly three full days and at one point affected 20,000 MW of customer loads (compared to an estimated total demand of 76,819 MW in ERCOT, if power plant capacity and fuel supply had been in operation and all customer demand could have been met).[32]
- This led to enormous hardship for millions of people, including days when people did not have power during extremely cold weather and when many people also loss of water supply. Several dozen people died.[33]
- The human toll also played out (or will play out in the future) in many consumers' pocketbooks, as high prices in natural gas markets combined with the shortage conditions in power markets translated into extraordinarily high prices in wholesale power markets. During the Texas power crisis, wholesale electricity prices average averaging over $6,600 per MWh and at times rose to $9,000 per MWh, compared to average prices in January 2021 of $21 per MWh. (See Figure 2.)

Figure 2:
ERCOT Average Wholesale Prices in Mid-February 2021, Compared to Other Time Periods[34]



[30] Department of Energy, Emergency Situation Report, February 17, 2021, at https://www.energy.gov/sites/prod/files/2021/02/f82/TLP-WHITE_DOE%20Situation%20Update_Cold%20%20Winter%20Weather_%20Report%20%232%20FIN.pdf.
[31] ERCOT 2-24-201 Presentation; https://www.smith.senate.gov/us-senator-tina-smith-calls-investigation-including-possible-price-gouging-massive-natural-gas-0.
[32] ERCOT 2-24-201 Presentation.
[33] https://www.texastribune.org/2021/02/19/texas-power-outage-winter-storm-deaths/; https://www.texastribune.org/2021/02/19/texas-water-power-outages/.
[34] ERCOT 2-24-201 Presentation.

- From a retail electricity consumer's point of view, those wholesale prices would equate to $6.6 (or even up to $9.0) for every unit of electricity used during that period, if those electric costs were passed through in retail prices. One electric industry expert calculated that a large home heated by electricity in Texas would have paid $4,500 in high electric bills for that week alone if that household's electric service agreement allowed for pass through of costs in the wholesale market.[35]
- Although most small electricity consumers in Texas purchase electricity based on fixed prices, a small percentage of households do buy power through products where the Retail Electricity Provider may fully pass through costs in the wholesale market. Customers with such service agreements are now getting eye-popping bills. And consumers served by municipal and cooperative utilities will eventually end up paying for their utilities' higher costs from February.
- The ERCOT market monitor has calculated that decisions by the PUCT and ERCOT during the crisis led to approximately $16 billion in overpriced electricity, and recommended that the PUCT recalculate and revise prices and payments retroactively[36] – something that the PUCT has elected not to do.[37]
- Meanwhile, state and federal investigations are underway to examine the outages and whether any price manipulation may have occurred.[38]

Clearly, these recent events in Texas are a chilling reminder of the critical role that reliable and resilient electricity plays in providing basic needs and access to critical services to households, businesses and other electricity consumers.

Research needs to enhance reliability and resilience of the electric system

Although the Texas electricity crisis was an unusual event, to say the least, there are many observers who have pointed out that such events could happen elsewhere in the U.S., and that steps are needed to proactively prepare the electric system to lower the risks of such occurrences and to lessen their adverse impacts. Although Texas' winter weather in February 2021 was extraordinarily cold, and colder than expected, it is now predictable that extreme weather events will occur more frequently and be more intense as a result of climate change.[39]

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[35] Seth Blumsack, "What's behind $15,000 electricity bills in Texas?" The Conversation, February 24, 2021, at https://theconversation.com/whats-behind-15-000-electricity-bills-in-texas-155822 .

[36] Letter from Potomac Economics to the Chair of the Public Utility Commission of Texas, March 4, 2021, at https://interchange.puc.texas.gov/Documents/51812_61_1114183.PDF.

[37] Paul Ciampoli, "Texas PUC declines to take action in response to report on $16 billion in additional costs," March 8, 2021, at https://www.publicpower.org/periodical/article/texas-puc-declines-take-action-response-report-16-billion-additional-costs.

[38] For example: Federal Energy Regulatory Commission News Release, "FERC, NERC to Open Joint Inquiry into 2021 Gold Weather Grid Operations," February 16, 2021, at https://www.ferc.gov/news-events/news/ferc-nerc-open-joint-inquiry-2021-cold-weather-grid-operations; FERC News Release, "FERC to Examine Potential Wrongdoing in Markets During Recent Cold Snap," February 22, 2021, at https://www.ferc.gov/news-events/news/ferc-examine-potential-wrongdoing-markets-during-recent-cold-snap; Garrett Hering, "In the wake of the storm, Texas PUC opens probe into outages," S&P Global Market Intelligence, February 19, 2021, at https://platform.marketintelligence.spglobal.com/web/client?auth=inherit&overridecdc=1&#news/article?KeyProductLinkType=2&id=62768135.

[39] For example: Academies' 2017 Resiliency Report"), at https://doi.org/10.17226/24836; Government Accountability Office, "Electricity Grid Resilience: Climate Change Is Expected to Have Far-Reaching Effects and DOE and FERC Should Take Actions," March 2021, at https://www.gao.gov/products/gao-21-423t; and J.M Melillo, T.C. Richmond, and G.W. Yohe, *Climate Change Impacts in the United States: The Third National Climate Assessment*, U.S. Global Change Research Program, at https://doi:10.7930/J0Z31WJ2.

Further, it is well-established that electric system infrastructure (along with other energy infrastructure) is vulnerable to such extreme weather events, with potentially risks to and costly impacts on human lives, public health, and economic activity. As the National Academies' 2017 report on Enhancing the Resilience of the Electric Grid pointed out:

> Electricity and the underlying infrastructure for its production, transmission, and distribution are essential to the health and prosperity of all Americans. It is important to make investments that increase the reliability of the power system within reasonable cost constraints. However, the system is complex and vulnerable. Despite all best efforts, it is impossible to avoid occasional, potentially large outages caused by natural disasters or pernicious physical or cyber attacks. This report focuses on large-area, long-duration outages—considered herein as blackouts that last several days or longer and extend over multiple service areas or states. When such major electricity outages do occur, economic costs can tally in the billions of dollars and lives can be lost. Hence, there is a critical need to increase the resilience of the U.S. electric power transmission and distribution system—so that major outages are less frequent, their impacts on society are reduced, and recovery is more rapid—and to learn from these experiences so that performance in the future is better.[40]

As I noted previously, I was a member of the Committee that prepared that 2017 consensus report. We made a number of recommendations relating to the need for greater research and development to support grid resiliency, which I present below. I also provide (below) a number of research-related recommendations from "The Future of Electric Power in the United States" (2021), which is recent report from a different Academies' consensus committee on which I also served.[41]

While the latter report focused on a much broader set of issues than enhancing the resilience of the electric system, it included grid resilience as one of the five major needs for the future electric power system[42]:

1. Improve our understanding of how the system is evolving.
2. Ensure that electricity service remains clean and sustainable, and reliable and resilient.
3. Improve understanding of how people use electricity and sustain the "social compact" to keep electricity affordable and equitable in the face of profound technological changes.
4. Facilitate innovations in technology, policy and business models relevant to the power system.
5. Accelerate innovations in technology in the face of shifting global supply chains and the influx of disruptive technologies.

In the context of this Science Committee hearing, I call your attention in particular to the Academies' discussion and conclusion regarding the essential role of federal support for RD&D on electric system issues:

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[40] Academies' 2017 Resiliency Report (preface).

[41] These two committees were chaired by M. Granger Morgan of Carnegie Mellon University, and like Granger and myself, several other members of the Future of the Electric System Committee also served on the Resiliency Study: Anjan Bose of Washington State University; Terry Boston, of Terry Boston LLC; Jeffrey Dagle of the Pacific Northwest National Laboratory; William Sanders of Carnegie Mellon University; and David Victor of the University of California, San Diego.

[42] National Academies of Sciences, Engineering, and Medicine, *The Future of Electric Power in the United States*, 2021 (hereafter referred to as the "Academies' 2021 Electric Power Report"), pages 3-7, at https://doi.org/10.17226/25968.

> The Department of Energy (DOE) is the federal entity with a mission to focus on the *longer-term* issues of developing and promulgating technologies and strategies to increase the resilience and modernization of the electric grid. No other entity in the United States has the mission to support such work, which is critical as the electricity system goes through the transformational changes described in this report. The committee views research, development, and demonstration activities that support reliable and resilient electricity systems to constitute a public good. If funding is not provided by the federal government, the committee is concerned that this gap would not be filled either by states or by the private sector. In part this is because the challenges and solutions to ensuring grid resilience are complex, span state and even national boundaries, and occur on time scales that do not align with business models.[43]

In the rest of my testimony, I will excerpt parts of both Academies reports, with a focus on their findings and recommendations that address federally supported research needs for a secure and resilient grid.

The Academies' 2017 Resiliency Report had several major overarching recommendations related to these issues:

> **Overarching Recommendation 3:** However the Department of Energy chooses to organize its programs going forward, Congress and the Department of Energy leadership should sustain and expand the substantive areas of research, development, and demonstration that are now being undertaken by the Department of Energy's Office of Electricity Delivery and Energy Reliability and Office of Energy Efficiency and Renewable Energy, with respect to grid modernization and systems integration, with the explicit intention of improving the resilience of the U.S. power grid. Field demonstrations of physical and cyber improvements that could subsequently lead to widespread deployment are critically important. The Department of Energy should collaborate with parties in the private sector and in states and localities to jointly plan for and support such demonstrations. Department of Energy efforts should include engagement with key stakeholders in emergency response to build and disseminate best practices across the industry.[44]
>
> **Overarching Recommendation 5:** The Department of Energy, together with the Department of Homeland Security, academic research teams, the national laboratories, and companies in the private sector, should carry out a program of research, development, and demonstration activities to improve the security and resilience of cyber monitoring and controls systems, including the following:
>
> - Continuous collection of diverse (cyber and physical) sensor data;
> - Fusion of sensor data with other intelligence information to diagnose the cause of the impairment (cyber or physical);
> - Visualization techniques needed to allow operators and engineers to maintain situational awareness;

[43] Academies' 2017 Resiliency Report, page 4.
[44] Academies' 2017 Resiliency Report, page 135.

- Analytics (including machine learning, data mining, game theory, and other artificial intelligence-based techniques) to generate real-time recommendations for actions that should be taken in response to the diagnosed attacks, failures, or other impairments;
- Restoration of control system and power delivery functionality and cyber and physical operational data in response to the impairment; and
- Creation of post-event tools for detection, analysis, and restoration to complement event prevention tools.[45]

Additionally, the Academies' 2017 Resiliency Report includes more specific recommendations related to federally funded research needs for the nation's electric system:

Recommendation #1 to DOE: Improve understanding of customer and societal value associated with increased resilience and review and operationalize metrics for resilience by doing the following: Developing comprehensive studies to assess the value to customers of improved reliability and resilience (e.g., periodic rotating service) during large-area, long- duration blackouts as a function of key circumstances (e.g., duration, climatic conditions, societal function) and for different customer classes (e.g., residential, commercial, industrial) (Study Report Recommendation 2.1)

Recommendation #2 to DOE: Support research, development, and demonstration activities, as well as convening activities, to improve the resilience of power system operations and recovery by reducing barriers to adoption of innovative technologies and operational strategies. These include the following:

- Initiating and supporting ongoing research programs focused on the operation of degraded or damaged electricity systems, including supporting infrastructure and cyber monitoring and control systems, where key subsystems are designed and operated to sustain critical functionality. (Study Report Recommendation 4.6)
- Continuing to support research and development of advanced large power transformers, concentrating to conduct several demonstration projects. (Study Report Recommendation 6.7)

Recommendation #3 to DOE: Advance the safe and effective development of distributed energy resources ("DERs") and microgrids by doing the following:

- Initiating research, development, and demonstration activities to explore the extent to which DERs could be used to help prevent large-area outages. (Study Report Recommendation 4.2)
- Supporting demonstration and a training facility (or facilities) for future microgrids that will allow utility engineers and non-utility microgrid operators to gain hands-on experience with islanding, operating, and restoring feeders (including microgrids). (Study Report Recommendation 5.6)

[45] Academies' 2017 Resiliency Report, pages 135-136.

Recommendation #4 to DOE: Work to improve the ability to use computers, software, and simulation to research, plan, and operate the power system to increase resilience by doing the following:

- Collaborating with other research organizations, including the National Science Foundation, to expand support for interdisciplinary research to simulate events and model grid impacts and mitigation strategies. (Study Report Recommendation 4.3)
- Supporting and expanding research and development activities to create synthetic power grid physical and cyber infrastructure models. (Study Report Recommendation 4.4)
- Collaborating with other research organizations, including the National Science Foundation, to fund research on enhanced power system wide-area monitoring and control and the application of artificial intelligence to the power system. Such work should include how the human–computer interface and visualization could improve reliability and resilience. (Study Report Recommendation 4.8)
- Leading efforts to develop standardized data definitions, communication protocols, and industrial control system designs for the sharing of both physical and cyber system health information. (Study Report Recommendation 4.9)
- Developing a high-performance utility network simulator for use in cyber configuration and testing. (Study Report Recommendation 6.12)

Recommendation #5 to DOE: Work to improve the cyber-security and other cyber resilience of the grid by doing the following:

- Embarking on a research, development, and demonstration program that results in a prototypical cyber- physical-social control system architecture for resilient electric power systems. (Study Report Recommendation 4.10)
- Developing the ability to apply physics-based modeling to anomaly detection, which provides real-time or better physics models that derive optimal power flow and monitor performance for more accurate state estimation. (Study Report Recommendation 6.8)

The Academies' 2021 Electric Power Report explains the five needs of the nation's electric system which I listed above, and includes recommendations relating to each one:

Regarding the first need—**#1: Improving our understanding of how the system is evolving**—the report states that:

> Because of many parallel changes in technology, patterns of electricity consumption, and social expectations for electric power, it is more difficult to forecast future electricity supply, demand, and infrastructure today than it was a few decades ago. The tools for forecasting electric futures need to be capable of adaptation because the architecture of the grid will evolve in different ways in different regions, and will adjust as the country reduces emissions of greenhouse gases from the overall economy through decarbonizing the electric supply and more pervasive use of electricity. As part of this effort, the nation needs to build and test new tools for simulation and experimentation to

understand how the grid of the future will behave and how operators and policy makers can ensure its continued reliability.[46]

The Academies' 2021 Electric Power Report includes research recommendations related to improving our understanding of how the electric system is evolving:[47]

Recommendation 4.5: Government support for key electricity research initiatives such as grid modernization and development of technology necessary for deep decarbonization should be sustained for sufficient periods of time to enable new areas of discovery. Congress should appropriate multiyear (minimum of 5-year) funding streams for proposed initiatives in key areas of national interest such as those identified, and DOE should implement long-term funding for projects that demonstrate alignment with critical national needs, technical success, potential net economic benefits, and cost-shared funding where appropriate. Such programs should follow best practices that include ensuring that DOE program managers have the knowledge and authority to oversee projects effectively and efficiently and clear criteria to govern advancement of projects.

Recommendation 5.5: DOE should support a sustained collaboration of national labs, academia, utilities, and vendors to develop a family of intercompatible simulation tools that have common standard interfaces to work together to assess the performance of the present grids and better anticipate the implications of the various ways the grid architectures may evolve in the future. As having a single large integrated model of very large, complex grids is impractical, the development and standardization of common interfaces between simulation tools will enable the studies of evolving architectures of generation, transmission, distribution, and ICT.

Recommendation 5.8: Because there will always be limits to what can be learned through simulation, DOE should choose the most promising new architectures indicated by large scale simulation studies in order to identify and plan a number of large-scale field experiments that could verify the advantages of such grid architectures under actual operations. Such field experiments of grid architecture would be qualitatively and quantitatively much larger in scope than the usual prototyping of a component such as a storage device, and should be reserved for when adequate resources and opportunities are available.

Recommendation 6.2: Owing to the increasing importance of computing, communications, and control technologies for the operation of the current and future grid, Congress should appropriate funds to the National Science Foundation, in consultation with DOE, to specifically focus on research programs exploring the implications and applications of rapidly evolving computing, communications, and control technologies on grid cybersecurity and cyber resiliency.

Regarding the second need for the future electric system—**#2: Ensuring that electricity service remains clean and sustainable, and reliable and resilient**—the Academies' 2021 Electric Power Report states that:

Reducing emissions of CO_2 and other environmental impacts of electricity generation will remain a major challenge in the coming decades. While the focus of the role of electricity generation on

[46] Academies' 2021 Electric Power Report, page 3.
[47] Academies' 2021 Electric Power Report. These recommendations (with their numbering reflecting the chapter in which they appear) are summarized on pages 8-9 of the report, with related discussion and findings found in chapters 4, 5 and 6 of the report.

ambient air quality may diminish as generation becomes less polluting, there is a growing focus on increasing sustainability and addressing climate change, in part through increased use of renewables. At high penetrations, this will require increasing the capacity of high-voltage, multistate transmission networks. The balance between reliability and resilience may shift over time but excellent overall performance will remain essential. The power system is vulnerable to a variety of natural events and accidental as well as pernicious human physical and cyber-attacks that can be minimized yet not eliminated entirely. New technologies, along with continued investment in critical elements of the electric power system, such as long-distance transmission and robust distributed resources, will improve the nation's capabilities. The nation, the electric industry and other stakeholders need to do a better job of educating and training people at all levels to design, reinforce, manage, and run a resilient and effective electric system.

The Academies' 2021 Electric Power Report includes research recommendations related to the need to ensure that electricity service remains clean and sustainable, and reliable and resilient:[48]

Recommendation 4.7: Given the structural, technological, economic, and operational changes under way in so many regions of the U.S. electric industry, it will be important for the federal government to fund and support research and analysis to help mitigate operational and planning uncertainties. DOE should sponsor research that will enhance the temporal flexibility of net electricity demand and enhance other services vital to grid reliability through pricing or other mechanisms. This will be important for supporting the entry of resources and services that can meet states' and consumers' desires for low-carbon electricity supply.

Recommendation 5.1: To meet the challenge of dramatically lowering U.S. CO_2 emissions, DOE, EPRI, universities, and industry should focus on developing: generation technologies with zero direct CO_2 emissions, low- carbon technologies with high dispatchability and fast ramping capabilities, storage systems for multihour, multiday and seasonal time-shifting; and power electronics to enable real-time control of the grid.

Recommendation 6.1: DOE's research program in grid cybersecurity is an important source of innovation to improve the resiliency of future grid infrastructure and operations. DOE should develop a regularly updated R&D priority roadmap in collaboration with the electric industry with input from academic and national lab researchers, and the vendor community. The R&D priorities in the roadmap should be funded by appropriations from Congress to DOE. The roadmap should be oriented to develop and demonstrate new technologies for resilient architectures that will enable energy delivery systems, and any interconnected systems, to be designed, installed, operated, and maintained to survive a cyber incident while sustaining critical functionality and enabling quick recovery.

Regarding the third need for the future electric system—**#3: Improving understanding of how people use electricity and sustain the "social compact" to keep electricity affordable and equitable in the face of profound technological changes**—the Academies' 2021 Electric Power Report states that:

Already many changes in the grid reveal opportunities for new services and configurations of electric resources. Some kinds of profound changes in electric supply, such as some customers

[48] Academies' 2021 Electric Power Report. These recommendations are summarized on pages 9-13 of the report, with related discussion and findings found in chapters 4, 5 and 6 of the report.

becoming less dependent on grid- delivered power, could be highly disruptive to the social compact that has been central to the electric power industry and its provision of universal service for over a century. These changes could have large impacts on customers with low incomes. It is crucial to build tools to understand those needs along with devising regulatory responses to evolve and selectively strengthen social compacts in light of changing circumstances.

The Academies' 2017 Electric Power Report includes a research-related recommendation relevant to the need to improve our understanding of how keep electricity affordable and equitable in the face of profound technological changes third need for the future power system is:[49]

> **Recommendation 4.9:** The increase in government funding identified in Recommendation 4.8 [relating to substantial increases in federal RD&D for the electric section, as discussed below under the discussion of the fifth need for the future power system] should include areas that have traditionally been neglected yet are vitally important to the future of the electric power system. Those include research to support planning, design, operation and control of grid systems as they face new challenges such as deep decarbonization and the need for resiliency against natural, manmade and cyber hazards. The consortium and multiyear approach of the Grid Modernization Initiative is a good model but must be funded reliably. Other traditionally neglected areas of research include the social science needed to inform policy and technology development.

Regarding the fourth need for the future electric system—**#4: Facilitating innovations in technology, policy and business models relevant to the power system**—the Academies' 2017 Electric Power Report states that:

> New technologies, such as clean generation, wide electrification, energy storage, power electronics, and systems for monitoring and control, can enable large changes in the way the power system is organized and operated. Especially large changes may occur in the distribution and retail parts of the grid where the system meets people and non-utility companies (the so-called grid edge"). While supply provided by central generation and transmission and distribution wires will remain essential, technical, policy and business-model changes could speed innovation and the introduction of new services to consumers at the grid edge. Understanding how electricity consumers behave, and how devices and energy services can be aggregated for supply, and how such trends affect system loads is emerging as one of most profound technological, regulatory and planning challenges and opportunities facing the future of the grid. That understanding requires situational awareness and control across potentially tens of millions of nodes and at high rates of response (milliseconds, not seconds). Such changes will require flexible system planning and operations at both the bulk-power and local levels.

The research-related recommendations related to the need to facilitate innovations in technology, policy and business models relevant to the power system include:[50]

> **Recommendation 3.6:** With support from Congress and state legislatures, DOE, state energy research organizations, and foundations should provide support for social science research

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[49] Academies' 2021 Electric Power Report. These recommendation is summarized on page 13 of the report, with related discussion and findings found in chapter 4 of the report.
[50] Academies' 2021 Electric Power Report. These recommendations are summarized on pages 8-9 of the report, with related discussion and findings found in chapters 4, 5 and 6 of the report.

and regulatory/policy analysis designed to identify and assess alternative models for regulation, innovation and industry structure in the retail/ distribution segment of the electric system. Such research and analysis efforts should also address opportunities and mechanisms to allow for flexible demand and the value of doing so for electric system performance, cost, and emissions. Such research and analysis should also focus on the development and assessment of metrics to measure how infrastructure investment decisions and authorized actions would affect carbon emissions. Such work should involve and be informed by industry, researchers at universities, think tanks and/or the national labs, and/or other institutions with research programs in the following fields (as well as others): energy economics, behavioral economics, public policy analysis, law, finance, and utility regulation.

Recommendation 4.6: Greater deployment of advanced electrical technology is essential and will require expanded support for DOE-backed demonstration projects, including through loan programs and support for industrial consortia that deploy critical technologies. Such expanded support should follow best practices in the implementation of technology demonstration and deployment programs. Programs should be designed for rapid learning (and course corrections where needed) and periodic assessment of the overall portfolio for its performance. Proposals for funded projects should include a clear articulation of how a demonstration could be commercialized including a budget for such activities—so that a larger fraction of successful demonstration projects lead to wider deployment.

Regarding the fifth need for the future electric system—**#5: Accelerating innovations in technology in the face of shifting global supply chains and the influx of disruptive technologies**—the Committee report states that:

Many of the basic power system technologies were first developed in the United States. However, the supply chains and manufacturing for most critical electric power system technologies have now moved offshore. The United States has been underinvesting in the innovation needed for future electric system performance. Massive new private and public investments are needed in innovation, especially for more cutting-edge technologies on which the future grid will depend. Policies are needed to move supply chains and manufacturing for those technologies back to the United States, while recognizing that innovation and manufacturing are now global. The United States must balance competing goals—one to gain from the advantages of a global search for innovative solutions and the other to ensure U.S. control and awareness of and access to critical grid infrastructure technologies. The advantages of engagement and awareness of progress overseas will be particularly important where grids are expanding in size and function, which facilitates testing, demonstration, and deployment of new technology.

Research-related recommendations related to the need to accelerate innovations in technology in the face of shifting global supply chains and the influx of disruptive technologies include:[51]

Recommendation 4.8: In order to meet the challenge of serving all Americans with safe, clean, affordable, reliable and resilient electric power in a rapidly changing environment, while building a stronger U.S. industrial base that can advance those goals, Congress should increase substantially

[51] Academies' 2021 Electric Power Report. These recommendations (with their numbering reflecting the chapter in which they appear) are summarized on pages 8-9 of the report, with related discussion and findings found in chapters 4, 5 and 6 of the report.

the overall level of support for RD&D on the production, delivery and use of electric power. Increasing such support too rapidly would lead to inefficiency and waste. This sets an upper bound on the rate and amount of increase. Over the next decade, support for basic science that is broadly related to electric power should be doubled, and support for applied development and demonstration related to electric power should be tripled.

Recommendation 5.2: The United States has lost ground in the manufacturing of conventional grid-scale power control technologies (e.g., HVDC and FACTS) and is deploying very little of these advanced solutions. Developments in rapidly growing technologies, such as PV, wind, EV, and energy storage, suggest a new paradigm may be rapidly emerging which is more modular, distributed and edge- intelligent, and which may be able to compete with and outperform the existing grid paradigm in terms of sustainability, reliability, resilience, and affordability. A rapidly changing paradigm for electrical power and the grid offer a unique opportunity for U.S. research and manufacturing to reclaim their global lead in this critical area. DOE, EPRI, other domestic and international research organizations, universities, and world-wide industry should identify such "breakaway" threads early, work with industry, investors and regulators to understand potential roadmap and impact. Then DOE, EPRI, and industry should collaborate to develop and fund a research agenda that creates fast-moving programs that help de-risk such solutions from technology, market and regulatory perspectives.

Conclusion

I hope that the Committee considers my testimony as it determines how the federal research agenda and programs might provide much-needed and valuable greater support for research in support of a secure and resilient electric system in the U.S.

Thank you for affording me this opportunity to present this information and my opinions to the Committee.

Bio of Susan F. Tierney, Ph.D.

I am a Senior Advisor at Analysis Group, an economic consulting firm headquartered in Boston, with other U.S. offices in California, Colorado, Illinois, New York, Texas, and Washington, D.C., and with international offices in Europe and Asia.

I have been involved in issues related to public utilities, ratemaking and electric industry regulation, electric system reliability and resilience, and energy and environmental economics and policy for over 35 years. During this period, I have worked on electric and gas industry issues as a utility regulator and energy/environmental policy maker, consultant, academic, and expert witness. I have been a consultant and advisor to private and publicly owned energy companies, grid operators, government agencies, large and small energy consumers, environmental organizations, foundations, Indian tribes, and other organizations on a variety of economic and policy issues in the energy sector.

Before becoming a consultant, I held several senior governmental policy positions in state and federal government, having been appointed by elected executives from both political parties. I served as the Assistant Secretary for Policy at the U.S. Department of Energy. I held senior positions in the Massachusetts state government as Secretary of Environmental Affairs; Commissioner of the Department of Public Utilities; Executive Director of the Energy Facilities Siting Council; and chair of the Board of the Massachusetts Water Resources Authority.

My Masters degree and Ph.D. in regional planning are from Cornell University. I previously taught at the University of California at Irvine and at MIT. I am a member of the advisory councils at Columbia University's Center for Global Energy Policy, New York University's Institute for Policy Integrity, and Duke University's Nicholas School for the Environment.

I currently sit on several non-profit boards and commissions, including as: chair of the boards of ClimateWorks Foundation and of Resources for the Future; a trustee of the Barr Foundation; and a director of World Resources Institute and of the Energy Foundation. I am currently a member of two Committees of the National Academies of Sciences, Engineering, and Medicine: the Committee on Accelerating the Decarbonization of the U.S. Energy System; and the Committee on the Future of Electric Power in the United States. I chair the National Renewable Energy Laboratory's External Advisory Council; I previously chaired the U.S. Department of Energy's Electricity Advisory Committee, and was a member of the National Academy of Sciences committee on resiliency of the U.S. electric system. I serve on the NYISO's Environmental Advisory Council. I was co-lead convening author of the Energy Supply and Use chapter of the Third National Climate Assessment. I previously served on the Secretary of Energy's Advisory Board, and chaired the Policy Subgroup of the National Petroleum Council's study of the North American natural gas and oil resource base.

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Chairwoman JOHNSON. Thank you very much.

At this point we will begin our first round of questions, and I will recognize myself for 5 minutes. Dr. Rai, you pointed out that ERCOT's strategy for implementing load curtailment in order to keep demand and supply roughly even while generation supplies were out was basically all or nothing. Rather than users curtailing part of their electricity demand by lowering their thermostats or cutting some of their electricity use, entire subnetworks were either on or off. Is this how Houston got into the infuriating situation where people were freezing in their homes and yet when they looked across the way at downtown, all the buildings were lit up and electrified with no one inside?

And the second question, how could a smarter load management strategy provide for more equity in grid operations during an emergency so that low-income neighborhoods don't take it all on the chin more than others? Dr. Rai, could you enlighten us a bit?

Dr. RAI. Thank you so much for that question, Chairwoman Johnson. Your sense is right. The severity of the supply disruption was so high that in many parts, in most parts of Texas only critical load and critical circuits were kept alive. Everything—all the load-critical circuits, a majority of them, were shed. And that meant that the noncritical load that are part of the critical load circuits that were kept alive, they also stayed on, and there was not much ability, again, just because of the severity and the depth of the event to rotate outages.

And so that's linked very much to your second part of the question, Chairwoman Johnson, in terms of being able to rotate the outages and being fair and equitable about it. It did mean that there were several parts across Texas where lower-income communities did have to weather more brunt of the whole event. And so as we heard from Ms. Garza, a much more granular approach to how this—these events are managed, the technologies do exist, but they do operate also in the underlying regulatory as well as operational context. And taking a holistic look at that is extremely important, but it is very possible and is one of the top priorities—it is one of the most low-hanging fruits there, Chairwoman.

Chairwoman JOHNSON. Thank you very much. Dr. Jenkins, you spoke in your testimony about the evidence tells us that caused these blackouts. I'd like to ask just a quick yes or no answer. *Forbes* published an op-ed in February of 2017 which claimed that a renewably sourced energy captures a larger share of the power grid. Outages become inevitable. Is this true?

Dr. JENKINS. No, that's not true. If power systems maintain sufficient firm generation that complement wind and solar, we can maintain reliability and expand the role of wind and solar, lowering costs and lowering carbon dioxide emissions.

Chairwoman JOHNSON. The Texas Public Policy Foundation published a statement in February—on February the 16th which claimed that fossil fuel electric generation didn't fail. Is that true?

Dr. JENKINS. That's not correct. We had over 30,000 megawatts of fossil generation capacity that was on forced outage during the crisis making up the bulk of the total electricity shortfall during the blackout, so natural gas power plants in particular were the largest absolute contributor to generation outages during the events.

Chairwoman JOHNSON. Thank you. In the same statement, the Texas Public Policy Foundation claimed that blackouts never would have been an issue had our grid not been so deeply penetrated by renewable energy sources. Is that true?

Dr. JENKINS. That's not correct. There was sufficient firm generation capacity installed that if it had operated as intended, it would have supplied adequate supplies for the system. The Texas system operator plans on as little as 1,700 megawatts of contribution from wind and solar power during extreme winter events such as that occurred in February, and so just a small fraction of what Texas was counting on to be there was wind and solar power. What Texans were counting on were natural gas and other firm power sources, and when those firm power sources fail, that's when widespread blackouts can occur.

Chairwoman JOHNSON. Thank you very much. My time is expired. I'll now call on our Ranking Member Mr. Lucas for 5 minutes of questions.

Mr. LUCAS. Thank you, Madam Chair. My home district in Oklahoma was also impacted by last month's winter storms and great interruptions. And while data is still being collected, one thing is clear. No single energy source, be it coal, wind, or natural gas, carries all the blame. The fact is a diverse supply of affordable, reliable energy sources is essential to the success of our power delivery system.

Ms. Garza, Mr. Torres, how will the adoption of new energy sources and hybrid energy systems affect how Congress and the Federal Government should be addressing grid security and resilience? And whichever one would care to go first.

Ms. GARZA. Well, you said my name first, so I guess I'll go first, Mr. Lucas. You—your comment was dead on. It—we all benefit from—I believe we all benefit from a wide variety of energy sources, and so with that we have to recognize common causes of failure across all of those sources. But just having more and different types of generation should prove to be more reliable rather than relying all on one.

Mr. LUCAS. Mr. Torres?

Mr. TORRES. Thank you for the question, Representative Lucas. What I see is that the evolution of renewables here, we're still at a state where we're not putting the same expectations on those renewables as we have on some of the legacy baseload types of generation or other fossil generation. For example, you know, I gave a testimony not long ago on black start, so putting those kinds of requirements so we can start to build that in to some of the new emerging technologies is really important.

One of the other differences is, as renewables are coming into play a bigger part of our energy portfolio, they're not located as just centralized generation plants but also as distributed resources. So now we can generate power, you know, at—near the loads at homes and businesses, and that gives us different opportunities to use renewables for things like microgrids to provide some local resiliency for critical loads. So this is actually—the new technologies are giving us new opportunities and potential that we haven't had before with strictly centralized generation.

Mr. LUCAS. This Congress I plan to reintroduce my bill, the *Securing American Leadership in Science and Technology Act*, which calls for the doubling of funding in DOE's Office of Science. Ms. Garza, what research is needed for technologies like advanced sensors and controls to assist the grid in emergency response?

Ms. GARZA. So the—so some of the challenges we face in terms of the outages and how those curtailments are managed, they are managed in a very blocky manner if you will. And how that works is a device in a substation is open, cutting off electricity to hundreds if not a couple of thousands of customers. And those actions are required to be taken very quickly, and that's how, you know, over the centuries we realized how to do it.

But technology exists to allow those very fast actions—I believe exist to allow those very fast actions to occur in a more granular level. We don't need to take out a whole feeder at once where along that feeder you could have some critical loads, there are some noncritical loads, there are some, you know, differing levels of reliability requirements for all of those customers. And by knowing that across your system, it seems like we could manage the reaction or the response in a much more granular and a much more targeted level than we're able to do now, and that in my mind requires software sensors, you know, all the whizbang stuff that needs to exist to allow that to occur.

Mr. LUCAS. Mr. Torres, in the time I have remaining how can fundamental research in areas like materials science and advanced computing support this work, this effort?

Mr. TORRES. I believe that there's opportunity to develop more inherently resilient materials that will comprise the grid of the future, so building your resilience into the system from the ground up, make it an inherent element in how we operate and how we design our systems. There is opportunities with things like artificial intelligence to help us better assess with forecasting information how to optimize operation of the grid. We can also utilize distributed computing to help us manage and operate the grid much differently than we do today where we operate in very, very centralized control architecture.

Mr. LUCAS. Thank you, Madam Chair.

Chairwoman JOHNSON. Thank you very much. And I will ask the Clerk now to assist us in going to our Members for questions.

STAFF. Mr. Bera is next.

Mr. BERA. Thank you, Madam Chairwoman and to the Ranking Member, for convening this hearing. Obviously, very timely and incredibly important.

I also, you know, appreciate the Raking Member's comments, but, you know, if we take the politics out of this, it's not, you know, one type of electrical source versus another versus another. It's what can we do to create redundancy here and redundant sources. And if we could remove the politics, you know, we could let the science and entrepreneurial spirit of America address these issues. And, you know, far too often it's the politics that prevent us from recognizing that our climate is changing, that we're having more extreme events that are occurring similar to the winter snowstorm in Texas but also in my home State of California. We see increasing wind events that have led to, you know, wildfires, you know, they have now led to rolling blackouts when we see the wind starting to pick up. And, you know, that is unfortunately going to become more common, not less common.

Part of the reason we have introduced in the last few Congresses the *Grid Security Research and Development Act* was we do have to make those investments in research in both the physical security of our electrical grid but also the cyber risk that our electrical grid faces. And, you know, I'm pleased that the Chairwoman and the Ranking Member, we passed it out of Committee and we passed it out of the House twice last year, did not quite get across the finish line, but we're going to reintroduce that act, which is bipartisan and, you know, get that through the Senate and get that to the President's desk. And we think that would be a big first step.

You know, maybe a question for Dr. Tierney. You talked about the Academy and some of the recommendations that the Academy was making in terms of research but also security. Could you expand on some of those recommendations and, you know, if we were to prioritize where we ought to focus, you know, what your recommendations would be?

Dr. TIERNEY. Thank you for that great question, Representative Bera. And speaking on behalf of myself, I think this—the bill that you plan to introduce is a very powerful tool to help with security and resilience in the face of cybersecurity events and other kinds of events as well.

So the 2021 report called "The Future of the Electric Grid" included a number of recommendations regarding congressional authorization, appropriations, and DOE implementation of RD&D related to cybersecurity in particular. First, one of the things that we called for was—is the updating periodically of research and development roadmaps with regard to cyber. The world is changing very fast in this way, and it—at the moment, the research agenda is not keeping up with the changes that are in place. That would involve a number of things associated with capability to visualize what's going on in the grid, information detection and controls, sensor data in order to capture that kind of information, critical needs for a workforce in this area that is really up to snuff. There are very serious needs in terms of developing the expertise.

I know you have limited time in here, so I'll stop there and follow up if you'd like.

Mr. BERA. OK. Fantastic. You know, it occurs to me that, you know, one of the—you know, our energy rates in California obviously are higher than the rates in Texas, and, you know, while the Federal Government doesn't dictate what States charge, you know, our user rates are higher because, you know, we have tried to create that redundancy and so forth. And, you know, my impression is Texas rates are lower because they had chosen not to, you know, do some of the physical measures to protect against these extreme weather events.

Again, I understand the independence of Texas and, you know, we can't go in there and tell them you've got to raise your rates and—what levers do we have, you know, again, wanting to protect the citizens of Texas from another extreme event like this? And, again, I don't know who best to answer that question, but, you know, what are things that we could do to compel Texans to do the right thing to protect their citizens?

Dr. TIERNEY. Well, it is the case that Texas is independent from a—from Federal supervision under the *Federal Power Act* on rates, but for reliability purposes, Texas is under the supervision of the North American Electric Reliability Council, and that has implemented authority from Congress through the FERC to address reliability. So there is room there under current authority to put much stronger incentives at least for Texas to adopt different behaviors.

Mr. BERA. Right. Just, again, knowing many Texans, my preference isn't to tell the Texans what to do. Congressman Sessions would get mad at me if I did that. But it's to work together as the United States of America to make sure we protect all our citizens.

So with that I'll yield back, Madam Chairwoman.

STAFF. Mr. Posey is next.

Chairwoman JOHNSON. Mr. Posey.

Mr. POSEY. Thank you. And I really appreciate Congresswoman Johnson for holding this hearing.

My questions are for Mr. Torres. Grid security is American security. Do you agree with that statement?

Mr. TORRES. I do.

Mr. POSEY. Thank you. Any component plugged into the grid must be beyond reproach and ideally a source from trusted suppliers that are not affiliated with or controlled by or manufactured by an adversarial country like China. This approach will support our energy independence. On page 8 of your testimony you rightly mentioned that the new rise in cybersecurity vulnerabilities are real, especially as it relates to new energy technologies, and one trend that is a challenge for the system resilience according to you is the loss in control and knowledge of the technology supply chain. Could you explain to this Committee how the Department of Energy has a system reliance challenge involving the loss of control and knowledge of the technology supply chain?

Mr. TORRES. Sure. What I meant to say there—and I can elaborate on that—is the fact that the grid and the elements that we're putting in the grid are driven by the market, and we operate and we procure energy components in a global market. And even when we purchase equipment and systems today from a U.S. vendor, that doesn't necessarily imply that everything in that system or device comes—is all manufactured by that vendor because they typically buy subcomponents, other software elements from vendors that can be global. It could be centered in other countries. It could be chipsets, it could be firmware, it could be software and other pieces of hardware that comprise the system that we don't necessarily always have full control over.

So understanding and providing some sort of guidance for how we can track what goes into those critical elements, especially when we're talking about things like black start and, you know, if the power grid entirely is blacked out, it could take days to weeks, maybe even longer to restart the—a large part of the grid. And so we have to be fully aware and confident in everything that's in the grid when we're restarting it.

So those kinds of things I don't believe exist, especially for those kinds of procedures don't exist in the policies and directions of where we're going with some of the newer technologies. We don't have the same expectations for some of the new technologies yet. We've been managing nuclear power plants and coal plants and gas plants for a long time, and we know how to do that, but we don't necessarily understand it as technologies are evolving what we need to do for things that may be added to the grid in the future.

Mr. POSEY. Yes, I hope that we can all agree it would be stupid for us to have power grids full of Chinese chip components. On May 1 of 2020, former President Trump signed an Executive Order 13920 to prohibit the acquisition of installation of certain bulk power system electrical equipment sourced from foreign adversaries that pose a demonstrated undue risk. Are you familiar with the bulk power Executive Order that was signed and suspended by the current President until April 20th with Executive Order 13990?

Mr. TORRES. Yes, I am.

Mr. POSEY. Do you know if the current Administration plans to reinstate the Executive order to ensure America's grid security?

Mr. TORRES. I do not know.

Mr. POSEY. If you find out, would you be kind enough to let us know?

Mr. TORRES. I will work with the Department of Energy to provide you all the information that I can.

Mr. POSEY. Thank you very much, Mr. Torres. Madam Chair, I yield back.

Chairwoman JOHNSON. Thank you very much.

STAFF. Ms. Stevens is next.

Ms. STEVENS. Thank you so much. Usually those of us in the North—Northern States make the quips about how our friends in Southern States, you know, aren't used to cold weather. The reality is in this case there isn't a quip to make because the crisis and the event that took place in Texas and in Oklahoma was catastrophic. And the history books will remember that the Chairwoman of the Science, Space, and Technology Committee brought us together for this hearing to get an understanding of the research needs that must go in to making sure that we have a grid that works. Lives were lost, people were put into tons of pain, business was impacted, and in the United States of America this is just something we never want to see, in the middle of a pandemic, mind you. So I appreciate all the expert and—you know, expert witness testimony here today.

I did mention that I come from Michigan, and much of our conversation as it pertains to the grid in my State is focusing on electric vehicles. And I did want to ask a couple of you—and I think you all may be equipped to lean in on this—but how equipped is our grid for the arrival of electric vehicles in the sense that they are right now comprising one percent of cars on the road with projection to go much higher than that? And even if we—you know, I think much higher than we are, we have to look at grid capacity. So I'd just—I'd be—you know, Beth, I see you're nodding your head. If you want to jump in, that would be great.

Ms. GARZA. So I think—thank you for the question. It's a great question. It's certainly one that's being discussed and deliberated in, you know, the energy policy world. There certainly are—there certainly is spare capacity currently in the distribution system to allow, you know, me or my neighbor to go get an electric vehicle and plug it in and we're—and that'll be fine. The questions then are, you know, once that becomes—you know, moves from 1 percent to 50 percent of the market, where are the stress points? Where do those exist? And I have every confidence that we can expand the grid and adjust the grid to manage that.

I think also required is the interaction between, you know, advance control aspects because, for example, you know, do you really want to be charging electric vehicles if there's a person next door that doesn't have electricity to their house because there's not enough supply, right? We have to be able to price and value the different uses of electricity, and we need the systems and software and techniques to be able to balance that.

Ms. STEVENS. Yes, thank you. And let's also just talk—you know I've got a minute and a half left. Let's just also talk about—and I'm sure my other colleagues are going to get into this—but the designing of a cleaner grid. So in a recent *New York Times* article, you know, they're obviously reflecting on 1/3 of America's greenhouse gas emissions are accounted for by transportation. You know, each year the electric cars and trucks are widely seen as a crucial part of the solution to climate change. It would also help if the electric grid that fueled these vehicles got a lot cleaner. Who has some thoughts about that and some of the ways in which we could make our electric grid cleaner?

Dr. JENKINS. Representative Stevens, I could answer that question. Thank you.

Ms. STEVENS. Yes, thank you.

Dr. JENKINS. Yes, over the next 10 years it would be possible if we continue to accelerate the pace of deployment of wind and solar, which I think we can do as these industries scale up, to increase the contribution of wind and solar from about 10 percent of our electricity today to as much as half by 2030. That would significantly help—that would help significantly reduce carbon dioxide emissions from the electricity sector, which is the No. 2 total source of emissions today, about 1/4 of our greenhouse gas emissions, by reducing the use of coal-fired and natural gas generation even if we keep the natural gas capacity around as a firm generation source.

And so we can reduce emissions probably on the order of 70 to 80 percent over the next decade in the electricity sector by scaling up technologies that are affordable and ready to go today. And we can use that same decade to proactively invest in the clean firm generation technologies that will ultimately need to replace or retrofit our existing natural gas fleet. If we do that, the power sector can help decarbonize transportation as well, as you noted, through electric vehicles, as well as heating through heat pumps.

Ms. STEVENS. Great, thank you so much. I yield back.

STAFF. Ms. Bice is next.

Ms. BICE. Thank you, Madam Chair. Thank you to all the witnesses this morning.

This first question quickly is directed at Ms. Garza. You mentioned earlier that forecasting is based on a 10-year lookback. Can you expand on that? Because that seems really unbelievable to me.

Ms. GARZA. So the weather conditions, using—so I'll be upfront and say as a utility industry—and I consider myself part of that—we're not the most creative folks, and so all we know to do is to—is what we have experienced. And when ERCOT looks at their—looked at their seasonal forecast, even their extreme weather forecast or the demand resulting from extreme weather for this winter, all they had in their records was the extreme winter we had in 2011. And that's—that—we—that was a bad—we had rolling outages then. That was a bad situation. That was the most extreme we'd seen, and so that was the basis of an extreme forecast. And, as it turned out, we suffered something worse than that, so we were not fully versed or fully aware of what the potential could be. And so understanding that potential is what I'm—was what I was trying to get at.

Ms. BICE. Thank you for clarifying that point. Mr. Jenkins, this question is for you. Would you be surprised to know that there has not been a nuclear reactor started online in over 30 years?

Dr. JENKINS. No, I would not be surprised. Actually, there was one reactor that had been restarted the TVA (Tennessee Valley Authority) brought online, but yes, it's been a long time since we started construction or finished a project on time.

Ms. BICE. So how do you think that the adoption of the newest technology, which is the small cell nuclear reactors, could actually play into the electric grid and actually address some of the concerns with availability of electricity on a large scale?

Dr. JENKINS. Yes, so new small modular reactors could be a more affordable source of clean firm generation capacity, along with advanced geothermal energy, hydrogen combustion turbines or fuel cells, and carbon capture and sequestration on natural gas or coal or biomass-fired power plants. So all of those options, which this Committee has supported in the past on a bipartisan basis, can be developed proactively over the next decade, can be introduced into the market, made cheaper over time, and can ultimately help contribute to a more resilient and cleaner electricity system.

Ms. BICE. I think that my point here is we've talked a lot about wind and solar but nobody has bothered to talk about nuclear. And although it's a very touchy subject, I understand that the dynamics of that, I think it's something we should be mindful of because nuclear sort of addresses some of the environmental issues that we see——

Dr. JENKINS. Yes.

Ms. BICE [continuing]. With, let's say, natural gas and coal. But the newest technology, which is just now coming around with these small nuclear reactors, actually provides an opportunity for us to increase capacity pretty greatly actually——

Dr. JENKINS. Yes.

Ms. BICE [continuing]. With less of an impact overall to anyone.

Dr. JENKINS. Yes, and if I could just emphasize also there are research needs that could help extend the life of our existing nuclear fleet, which is our largest source of carbon-free generation and a key foundation to build on going forward.

Ms. BICE. And I'm for your deal in investing more in research. I'm sure this Committee on a bipartisan basis would also agree with that.

My last question, we talked a lot about the challenges with Texas and the impact of the natural gas shutdown. This question is for anyone. Do you believe that the winterization of the natural gas delivery and production could have prevented the large-scale failure that we saw? I think it was a 30 percent reduction in delivery capacity.

Dr. TIERNEY. I think this is a very important issue, and I'm really glad you brought it up. The incentives need to work to make sure that the generators are arranging for gas in a winterized way so that the gas supply can be helpful in critical periods like Texas just experienced. The National Academies report calls for a—an effort to make the gas industry processing production delivery system more reliable and visible, along the lines of what we already have on the electric side, so there is a lot of work could be done there.

Dr. RAI. I think something I can add there is in terms of the visibility I think there is a lot of scope in terms of how the production happens and how it is impacted. It is—we are still finding out exactly what the impact was upon production losses because of winterization. The general answer is yes, it would have helped, but there's a lot of, you know, information needs and visibility needs there as well.

Dr. JENKINS. Yes, we——

Ms. BICE. Yes, I'll just close—I'm sorry, go ahead.

Dr. JENKINS. I was going to say and it goes both directions, so they were losses of power to compressor stations that are needed to keep pressure up in the gas pipelines as well, and so the interlinkages of these two systems is critical and needs to be explored and strengthened.

Ms. BICE. And I'll just wrap up my closing by saying that I think that we've learned a little bit about making sure that infrastructure across the United States, whether it be in Texas or in California, that we're keeping up with maintenance on that infrastructure to prevent things like huge power outages or wildfires from occurring because of the lack of infrastructure upkeep. I yield back, Madam Chair.

STAFF. Ms. Wild is next.

Ms. WILD. Thank you very much. Thank you, Madam Chair, for convening this hearing.

My district is one of the districts in Pennsylvania. Pennsylvania has long been an energy leader in our country. And one of the things that I really wanted to get into is Pennsylvania is connected to a multistate grid, PJM Interconnection, which moves electricity from New Jersey down to South Carolina—excuse me, North Carolina, and as far west as Illinois covering all or some of 15 States and the District of Columbia.

Drs. Rai and Jenkins, I wanted to ask you, how can multistate and regional grids reduce the risk our grid faces from severe weather and other threats relative to single state grids? And I'll just go ahead and ask the rest of the question. You can cover it as you will. What benefits would multistate grids offer for reliability and resilience as we transition toward renewable energies like solar and wind?

Dr. RAI. Thank you so much——

Dr. JENKINS. I——

Dr. RAI. Thank you so much for that question, Ms. Wild. The answers are—there's a lot of questions in there. The last major studies about the value of interconnecting ERCOT [inaudible] to the other two grids were done a couple decades ago or over that. There have been other studies, smaller studies but really not a very big, significant. Times have changed a lot. Technologies have changed a lot. All three grids have experienced increased penetration of renewables. And as Dr. Jenkins mentioned, that is a trend that is going to only grow. There is a very strong and immediate need to take a much more careful leap.

It is just like, you know, how our source of natural gas helped us in hard times. We reach out for water, for food, for support. These interconnections were just the same way. If you're impacted differently, there is a lot of support and supplies that can act—that can be accessed through these interconnections. And it actually did happen even during this crisis for parts of the interconnection bringing in some power from the Eastern into the midcontinent region as well.

Ms. WILD. Dr. Jenkins, did you want to add something to that?

Dr. JENKINS. Yes. No, I second everything that Professor Rai just said. Just one thing to add is that I know that Texas has deliberately stayed out of the Eastern interconnection or Western interconnection in order to maintain its independent, State-run electricity markets. That could continue to be maintained while expanding direct-current inter-ties with the rest of the Eastern or Western interconnect. There are some existing transfer capacities between the two—between the Eastern interconnect and Texas and between Mexico and Texas. Those could be extended or expanded particularly into the West, and to the Western interconnect as well without synchronizing the ERCOT grid with the rest of the system. And so there's not really, you know, a tension there between greater—a greater ability to import and export power and the independence of the ERCOT market. And I think that's an area that Texas should consider how much of that investment is worthwhile going forward.

Ms. WILD. OK. Well, thank you. That's very illuminating. I also wanted to focus on storage a little bit, which is one of the issues that energy sector executives in my district talk about all the time in connection with clean energy transition, the need for scalable, efficient, and affordable energy storage so that our grid will stay reliable. How would that kind of energy storage capacity have lessened the impact of the extreme weather in Texas?

And my follow-up is what research questions should the scientific community and DOE investigate to ensure that energy storage capacity is resilient?

Dr. JENKINS. So I would say that the bulk of the energy storage capacity we are adding to the grid today are lithium-ion batteries, the same kind of battery storage in electric vehicles. Those are very affordable and getting cheaper every year and provide a lot of flexibility on short timescales over the course of a few hours.

Unfortunately, in this crisis if Texas had more battery storage capacity, it would've helped at the beginning of the crisis, but those batteries would have run out of power on Monday and, you know, not provided much more beyond that.

So in terms of research needs, you know, there are other reliability and resiliency threats the shorter-duration batteries can help with other than these sustained outages and also longer-duration energy storage technologies that could provide sustained output for days or even weeks could potentially play a larger role in these sorts of events.

But ultimately, you know, long events like this require firm generation capacity that can sustain its output without an energy limitation that storage has.

Ms. WILD. Thank you. And, Dr. Rai, did you want to add anything to that in my last 15 seconds?

Dr. RAI. Just very quickly that there is a very important need to also look at large-scale demand-side engagement and how that can be engaged even for longer durations because that's a very tough nut to crack with storage for a long time.

Ms. WILD. Thank you so much. With that, I yield back, Madam Chair.

STAFF. Mr. Feenstra is next. We can't hear you, Mr. Feenstra. It looks like you have a headset connected.

STAFF. Mr. Feenstra, next to where you can mute and unmute, there's a little triangle or you can click on that and check and see what audio devices you are using. Still cannot hear you. No, sir, still cannot hear you.

Mr. FEENSTRA. Can you hear me now?

STAFF. We can hear you.

Mr. FEENSTRA. Sorry about that. I just wanted to say thank you, Madam Chair and Ranking Member Lucas. Before I start, I just wanted to thank each of the witnesses for their testimony and sharing their extensive research and educated opinions with us.

You know, the weather this February in Iowa, you know, we saw a lot of the drastic things. Our temperatures dropped below 28 below 0. We had 24 inches of snow. Part of my district, yes, we saw rolling blackouts and it was a pretty big deal. It's important that we all do what we can to protect and modernize the grid that we have to ensure the resiliency and protect from these large-scale rolling blackouts.

So the question is for Dr. Jenkins. You highlighted the importance of clean electricity to an affordable transition to a net zero emissions economy in your testimony. My district in Iowa is one of the top wind energy areas in the country. New wind and solar generation is in our region but is tremendously bottlenecked by the transmission constraints. Mason City, a town in my district, will be the home to one of the two power converter stations for an organization called the SOO Green HVDC (high-voltage direct current) Link transmission line. This line will power renewable energy from Iowa into northern Illinois with—being connected with a PJM power market.

So this is my question. How do we create transmission lines like this that create redundancy and increase clean energy availability and transport this energy to densely populated regions like the East Coast and Chicago and things like that? We're trying to do this in Iowa, but again, we have a tremendous bottlenecked that is going on with our transmission.

Dr. JENKINS. Yes, as you know in Iowa and across much of the country we have an incredible American resource in the form of wind power, as well as solar energy potential across much of the country, but to use that effectively, we have to be able to bring that energy from where it's generated to where we consume it. It's much the same as with our natural gas and oil resources in the country or our coal resources where we have to build the natural gas pipelines and the rail lines to bring, you know, natural gas and coal to where we need it.

And so a modern transmission system that is built to export wind and solar power from where it's cheapest to our cities is a critical piece of an affordable and more resilient electricity system that will benefit economically those exporting regions.

And there are research needs as well that could help us improve the cost of direct-current transmission lines, the converter stations and other components of those systems, as well as identify cheaper ways to underground lines, which could help reduce public opposition to expansion.

So it's a—maybe I'll defer to Ms. Tierney for more on the regulatory side of things, but there are significant research questions there for us to think about as well.

Mr. FEENSTRA. And that's a great point. I mean, this line is an underground line running adjacent to the railroad system——

Dr. JENKINS. Yes.

Mr. FEENSTRA [continuing]. So it's a perfect line, secure and everything like that. I'm going to ask any one of you. I mean, what incentives would you look at it to try to create private-sector dollars to create these transmission lines?

Dr. TIERNEY. Could I start by saying that in most instances it's not financial incentives that are the problem with bottlenecking the lines. It is really related to ensuring that there is public participation in the process and ensuring that there are regional issues that are taken into consideration in the siting of new transmission lines.

The National Academies report has requested that Congress enact and declare a new national transmission policy that not just is about resiliency and reliability but it's also about opening up regions of the country with very high-quality wind resources, for example, and that that is something that should be taken into consideration when States and the Federal Government are acting to approve lines.

The SOO line is pretty amazing in terms of how it was developed and sited, and I think it's a great example of the kinds that we should see in the future.

Dr. RAI. Mr. Feenstra, if I could add quickly, one of the great examples of infrastructure investments in Texas has been bringing much of the wind that is generated in the western side of Texas into the load centers much to the south and the east, and that was done over a period of about a decade with over $7 billion of investment. And that required as—just as, you know, Sue mentioned, a lot of public participation, as well as a very long and detailed regulatory process to get into that. But it was done and it has played a tremendous role in diversification of the energy system here in Texas and will be important in the future as well.

Mr. FEENSTRA. Yes, thank you for both of your comments on that. I absolutely agree. I think the other big issue is a regulatory issue with SOO Energy and these organizations that are trying to do transmission lines. They're really struggling. It takes years to get regulatory approvals on these things, and if we could turn down that timeline, that would be fantastic. Thank you, and I yield back.

STAFF. Mr. Bowman is next.

Mr. BOWMAN. Thank you, Madam Chair and Ranking Member Lucas, and thank you to our witnesses.

Dr. Rai, you emphasized a need for better communication and coordination in events like what happened in Texas and the need to organize a voluntary reduction of demand. When it comes to threats to the grid and energy shortages, do you have additional thoughts on how we can design emergency preparedness efforts so that they are truly community-driven and equitable? Are there any precedents for how this can work well that you have in mind while crafting your testimony?

Dr. RAI. That's a great question, Mr. Bowman. I would like to just remind as—I was, you know, with my family during the crisis, and it was in utter chaos after a couple days in the household. Literally—and there was very little coordinated information that was coming to us. We were banking on neighbors and, you know, other friends for any little bit of information other than high-level system information.

When—in times of—there is a lot of precedents. For example, in times of major hurricanes, there is a lot of great work that has happened in this country over the last several decades. There is a lot of great infrastructure and significant investment that goes on into weather forecasting and emergency system preparation. When ahead of time information is shared, then people pair up, people get ready and leave, get to safety.

It does tie back to security concerns and in particular that is an added complexity in the electricity system. If an event like this further gets complicated, as was mentioned by Dr. Torres, that in events like this further in the restart process, in the black start process you have additional cybersecurity-related threats, that can really complicate matters a lot. So, you know, I would say when multiple events can really get out of control, really focusing on those events and crafting solutions that take those matters into consideration.

Dr. JENKINS. Could I just add to that briefly——

Dr. TIERNEY. Well, on the equity question——

Dr. JENKINS. Sorry, go ahead, Sue.

Mr. BOWMAN. Please.

Dr. TIERNEY. Well, on the equity question there are things that utilities are doing around the country in vulnerable areas where there are disadvantaged populations. There are prepositioning of community heating or cooling centers where there's—that that will remain connected to the grid as a critical service area. There are prepositioning of crews to help with addressing restoration of service. And those are all part of a resilient grid, you know, planning and getting it ready for when you need it, and that's really important for folks who just really need electricity for heating and cooling.

Dr. JENKINS. Yes, I was just going to echo that, that it's not just the resilience of the system but also our preparedness to respond when accidents and crises do strike that leads to the human cost of these crises, and so anticipating these kinds of extreme weather events and better preparing for them, particularly with a focus on the most vulnerable populations, can make a huge difference in the—you know, the economic and physical human toll of these kinds of events.

Dr. RAI. Mr. Bowman, very quickly, one other point——

Mr. BOWMAN. Yes.

Dr. RAI [continuing]. Of the story is how much local community and local leaders got together and really got the State and our communities through this. It was one of the biggest, most powerful untold stories, but the truth is that in events like this, which might actually get more frequent, we cannot let it down to the households and the communities to always fend for themselves. There is need for Federal and State action at a very high level.

Mr. BOWMAN. OK. Thank you all very much for those answers. I yield back my time.

STAFF. Mr. Obernolte is next.

Mr. OBERNOLTE. Well thank you very much to our panelists. This has been a fascinating discussion. My first question is for Dr. Jenkins. You said something in your testimony that I found very interesting. You attributed a lot of these failures to a failure to require contingency plans, and you said some interesting things about risk when you draw an analogy with insurance policies. So I wanted to ask you about that risk, because, in my home State of California, one of the risks to power generation is earthquakes, and what you quickly find is there is no way to completely insulate power generation from that risk. You know, you have to accept that a certain severity of earthquake is the one that you're planning for, and that, you know, that anything beyond that is going to affect your resiliency. And so I'm wondering, you know, how do we parse this risk? I mean, at what point do we say that we want our grid to be 99.99 percent resilient, but not .999 percent resilient because it would be too expensive? How do we do the math on that?

Dr. JENKINS. Yeah, I do think it's a challenging equation, and the threats that each region faces are going to be different, and that's one of the things I tried to emphasize in the testimony. So for Texas it might be these extreme cold events, but elsewhere it's wildfires, or earthquakes. So I'd say there's two things. One is to think about the relatively cost-effective measures that can be taken to push back that failure mode, so that it's a little bit stronger earthquake before things go down, or a little bit colder temperatures before the system fails, and there are a number of these measures that are quite affordable. You know, winterization of wind turbines, for example, heat tracing of critical sensors and feed pipes, for example, as resilience to cold, that could've been taken in Texas, indeed were pointed at in previous reports, and in many cases were just not taken or not maintained.

And so there are some—first some affordable things that can be done to push back the breaking point. And then the second thing, which I think we're emphasizing in the response to Congressman Bowman's question, is that we also need to think about how we respond, and I think in earthquakes that's, you know, something California is well prepared for, right? The—you do know that earthquakes are a risk, and there are emergency and contingency plans in place. And I think what climate change means is that we have to check our blind spots on those kinds of, you know, weather-related risks because, you know, if the 2011 storm in Texas was used as the high water mark for, you know, for the threat, and the reality was that that was inadequate to plan for the severity of, you know, what could've been possible.

So that's where future climate research that could better—help us better understand how those extreme threats are evolving, and what steps could be taken to better prepare for them would be very helpful, because the past——

Mr. OBERNOLTE. Sure.

Dr. JENKINS [continuing]. As I said, is not a good guide for the future anymore.

Mr. OBERNOLTE. Right. Well, I think your point is that there were steps that could and should have been taken in Texas that were reasonably cost-effective, but I think everyone needs to realize that a 100 percent resilient grid is statistically impossible, and at——

Dr. JENKINS. Exactly, yeah.

Mr. OBERNOLTE [continuing]. Some point you're going to get to a level where the additional cost is not worth the reduction in risk. So——

Dr. JENKINS. Yeah. And——

Mr. OBERNOLTE [continuing]. There's always going to be a point at which, you know, the grid could statistically fail.

Dr. JENKINS. That's right, and that's why I'm—in the response side of things too, because it's a question of cost and the, you know, the risk your mitigating, and if you can use operational strategies and responses to these crises when they—when systems do fail to minimize the cost, then that also means you're less vulnerable as well, so it's both sides of the equation that we have to pay attention to.

Mr. OBERNOLTE. Right. Thank——

Dr. RAI. Mr.—if I may add a couple points here? I would just want to remind that there were three major things that could have been done that did not really require a massive, you know, long-term investment or rethinking. I mean, I had already pointed out—you know. Winterization does also include engaging with demand, as well as, you know, very simple things, as, you know, what really is your critical load, right? Keeping track would have been very simple.

Something I think is very important to keep in mind, as I mentioned in my testimony, the scale of the damages, right? You know, we cannot just look at, you know, what was, you know, what was the value of the loss to—there are damages to water infrastructure, there are economic damages, there are governments, you know, local governments failing, and when you bring those things in, early estimates are putting that over $100 billion, and my back of the envelope calculations say even if you were to require winterization of the entire gas and power infrastructure, it is not going to be of the same state. It's going to be an order of magnitude lower, right? So, you know, you need to keep both sides of the equation in mind to really find out what the balance is.

Mr. OBERNOLTE. Sure, yeah. I think we all can agree on that. And, Dr. Rai, while I've got you here, let me ask a last question. You said something in your testimony I thought was very interesting, which was that one of the biggest failures, in your opinion, was a lack of voluntary demand reduction. And I just wanted to ask, you know, how we would go about affecting voluntary demand reduction, because the traditional way is to do it through market pricing, which happened in some parts of Texas. And I think in retrospect we look at that and realize that it was too quick, people didn't realize the high price that they were paying for power, and that probably that's not a good way of going about it in the future. So how should we go about it?

Dr. RAI. That's a great question. Voluntary reduction doesn't mean it should be free, you know, it—just that, you know, it was not—you can't enforce it, but when there are disruptions of this scale—and just as you mentioned, you cannot completely 100 percent proof things, so we should be expecting disruptions like this here and elsewhere. In those types of situation, really engaging in messaging, and engaging that demand becomes very important. And I have offered—I don't pretend to have all the solutions, but that's so important, such a big possible part of the question, that it needs to be studied further.

Mr. OBERNOLTE. Yeah. Well, in other parts of the country we have voluntary reduction programs where, in return for a lower electric rate, large industrial consumers agree to, on demand, reduce their consumption, right? But I don't think that that is on a scale that would be big enough to solve the problem in Texas. So, it's something that certainly bears further discussion, because I don't see how we get from where we are to where we want to be.

Dr. TIERNEY. And much more social science research.

Ms. GARZA [continuing]. In on that. I'm sorry, Sue. If I could chime in on that, you know, ERCOT is a summer-focused electric system, and we do have significant demand programs reacting and responsive to the—in the summertime. And one of the limitations was the, you know, the limitations of those programs and those services, their availability in the winter, so——

Mr. OBERNOLTE. Well, great. Well, I see we're out of time, but thank you very much for your testimony. It's been a fascinating discussion. I yield back.

STAFF. Mr. Casten is next.

Mr. CASTEN. Thank you, Madam Chair, and it's so nice to see so many old friends on this panel from my prior life in the energy world. Want to start with a couple questions for Dr. Jenkins, a couple short ones, and one sort of medium one. First one, El Paso had about the same weather. Did they have any outages in this recent period?

Dr. JENKINS. I don't believe there were any rolling blackouts, but I could be wrong about that.

Mr. CASTEN. Is there a simple reason for that?

Dr. JENKINS. Well, I'm not sure it's a purely simple reason, but they are connected to the rest of the Western Interconnect, and so they could draw power from much further away, and conditions were not quite so cold.

Mr. CASTEN. So they're outside of ERCOT?

Dr. JENKINS. Yeah. They also, I think, took more proactive steps to weatherize their system, and I understand it.

Mr. CASTEN. So, to that point, I'd like to ask unanimous consent to introduce a document for the record. It's entitled "Outages And Curtailments During The Southwest Cold Event Of February 1 Through 5, 2011" from FERC and NERC. Dr. Jenkins, are you familiar with this report?

Dr. JENKINS. Yes, I am.

Mr. CASTEN. It strikes me that some of their recommendations talking about what should have happened in 1989, and weren't done in 2011 and is it safe to characterize this report as saying that the events that recently happened in Texas were not only foreseeable, but were actually foreseen?

Dr. JENKINS. Yes, I think that's correct. You could almost do a find and replace for the dates in the 2011 study and replace 1989 with 2011, and 2011 with 2021, and it would still read, you know, very similar to the reports that I'm sure will be released after this event. It's kind of eerie.

Mr. CASTEN. Well, I raise that because I really want to impress on my colleagues to please read this report, because there is an understandable political bias for everybody to say we couldn't have seen this coming, and we did, and we need to make sure that we incorporate those recommendations.

Somewhat meatier question for you, and I do want to get one question for Dr. Tierney, so I apologize—brief here, the North American Reliability Council imposes all sorts of requirements on load serving entities on the electric grid that have—requirements for backup generation, and redundant transmission, and one in—1 day in 10 years outage requirements, you know, all those details. Is there an equivalent standard for natural gas infrastructure?

Dr. JENKINS. Not that I'm aware of, but I'd defer to the other panelists if they know more.

Mr. CASTEN. Well——

Dr. TIERNEY. No, there is no such reliability organization or standard for the gas industry.

Mr. CASTEN. So as we get to grids that are more gas dependent, should we be thinking about something like a standard like that for the gas industry? Because it strikes me that that's the weak point in our system. And, Dr. Tierney, I have a follow-up question for you, but since you jumped in, go ahead.

Dr. TIERNEY. Yeah. I want to make sure to highlight the recommendation of the 2021 National Academies study on the future of the grid, where we call for Congress to do exactly that. So it's a very important thing, given this interdependency between the two energy systems.

Mr. CASTEN. So I want to pivot there, and, Dr. Tierney, I'm glad you jumped in, because, as a fellow former New Englander, the—I've always thought of ERCOT as being the New England ISO with less interconnect and more electric heating, as far as the dynamics that affect it. And, you know, I mention that because we have these issues where, when systems get tight, gas is preferentially dispatched for heating, as it was, except that in New England there isn't this huge surge of electric heating load that comes on.

And as we think about how to do what we must do to get to a zero carbon future, we've got a national policy that broadly talks about let's get to zero carbon in the electric sector as soon as we can, and then let's "electrify everything." And Texas is in many ways sort of a microcosm, if not all the way down that path, but the beginning of it, because loads that are done—that are served with other fuels in the rest of the grid are significantly served with electricity in Texas, and we've got that constraint on the system.

As we talk about an infrastructure while going forward, the—given as the, you know, if my math is right, you know, roughly—a little less than 40 percent of the total energy used—this country for electricity, almost 50 percent is for heating, in the industrial—commercial industrial sector. If we are going to electrify everything, and we are going to shift to a zero carbon electric grid, the implication is that we are massively increasing our generation fleet, we are massively relocating the generation fleet, and we're massively relocating where the load is, and we'd better be talking about transmission.

So what should we be thinking about—this—set aside who pays. What is the quantum of money we need to be thinking about, round to the nearest $10 billion if you need to, to invest in a transmission system that is actually going to enable us to connect clean generation to an electrified load?

Dr. TIERNEY. I don't have my number at my fingertips, but I would be happy to provide you with information after the hearing, if that would be helpful. I completely agree with you that transmission plays an absolutely critical role here. We know from many NREL studies, where Dr. Torres is located, that bigger regions interconnected, and transmission-enabling those bigger regions to perform, is really important. Where you are living today, there are these various interconnections across different regional transmission organizations. Those need to be bulked up, and certainly New England is interested in enhancing its transmission capability to a variety of diverse areas where there are high quality—in a stimulus package there can be things that Congress would adopt as part of financial incentives to get shovels, or, let's see, electrical wires put in place on the system.

Dr. JENKINS. If I could add to that, Representative Casten, the Net Zero America study that I helped publish at Princeton, which looked at this transition over the next decade toward a net zero emissions economy, estimated on the order of $350 billion in incremental investment in transmission over the next decade alone. That'd be about a 60 percent increase in transmission capacity over the next 10 years. This is a huge undertaking, a huge opportunity for investment and job creation as part of an infrastructure package.

Mr. CASTEN. All right. I'd love to follow up with all of you. I'm out of time, but I do just want to leave this to comment here that the scale of what we are talking about in transmission in our infrastructure plan is a tiny, tiny, tiny fraction of that, and we don't start to grapple with the numbers you're talking about, we're going to be wrong-footed. So let's continue the conversation. Thank you, and I yield back.

Mr. TORRES. Mr. Casten, if I could just throw something in there? There's a set of electrification future studies that we've been conducting with the Department of Energy that really helped you—helps us understand how the loads will grow across the different sectors, and that would be very useful in the planning. Thank you.

Mr. CASTEN. Thank you.

STAFF. Mr. Garcia is next.

Mr. GARCIA. Yeah, thank you very much. Thank you, Madam Chairwoman, and Ranking Member Lucas, for pulling this together, and thanks to the witnesses. This is an absolutely critical discussion, and what we saw in Texas last month was a tragedy. It was heartbreaking, and, in my opinion, was something that we, as Americans, should have been able to prevent.

I represent a district in Southern California that these types of scenarios are not foreign to us, unfortunately. It's not necessarily the extreme cold, but in our case it's the extreme heat, and it's the winds, that have led to, in my district, close to 30 power outages in the last—call it 10 months. We don't live in Venezuela. We live in the United States of America, yet our utilities behave, and the public utility companies responsible for power generation in our State, behave as if it is Venezuela. These problems are a product of challenges provided by Mother Nature, but it is mankind, and the folks responsible for our utility companies, and those who represent us in government, who are responsible for the failure. We have failed to overcome the challenges that Mother Nature has provided, and I resonate with the comments by my colleague, Mr. Casten, that this is a repeated lesson learned over the last several decades.

In my district we lose power when the winds get above 30 miles per hour. That's not a scenario that one would call a force majeure. That's not an anomaly, especially not in Southern California. That happens on a very frequent basis. We've lost lives, we've risked thousands of lives, we've been surrounded by flames while we have no power, and we've been effectively not only losing our power, but also our water, because many of my constituents are on wells that are electrically driven.

So my question to the panel, and I think we can start with Mr. Torres, is how do we ensure that we're not playing whack-a-mole here across all 50 States and our territories? How do we ensure that what we saw in Texas doesn't happen in other States? Maybe not for the same reasons, maybe for different reasons, and that these lessons learned that you are collecting as a result of the incidents in February in Texas are being disseminated? And it may not be for cold weather, but this grid hardening and the lessons learned, what venues, what media forum, summits, and/or discussions are you having to make sure that the lessons learned from Texas, California, and other States are being applied to the rest of the United States so that we're not playing whack-a-mole here indefinitely?

Mr. TORRES. All right, thank you, Mr. Garcia. I can't speak to all the things that are going on. I can talk to some of the things that we've been doing within—in realm of the Department of the Energy through the GMI activities and grid modernization—those are strong collaborations across the industry with the utilities, with the vendors, the various stakeholders. And I fully agree with you that we really have a patchwork of perspectives and policies across the different elements of the grid, and there needs to be more communication, discussion, as to what are the roles, responsibilities, and the implications of those differences? Because we're all trying to achieve a common good here. We all want our lights to stay on. We want to avoid major events like this, and so we need to understand what should each part be for every member? What can we be doing? And what are the changes that we're—that the different participants are implying? How could that affect the overall resilience of the grid? And can there be opportunities for shared costs, shared investments? Those kinds of discussions I totally agree need to continue so that we can avoid and mitigate some of these kinds of disasters.

Mr. GARCIA. Thank you, sir, and I would just submit to this body, and all of us at the Federal level, that our investments in research into the grid hardening and expansion efforts should include not only the conduits of power between cities and generation plants, but also conduits between entities and bureaucrats who are responsible for making sure lessons learned are proliferated as well.

I personally believe that we need to hold the public utility companies accountable for this. This is negligence. This is loss of life. This was foreseeable in many cases, and we as Americans deserve better than this. I thank, again, the Chairwoman for opening the aperture on this a little bit further, and I just want to reinforce to my colleagues that this is not a problem unique to Texas. We will lose more Americans in other States as we start seeing some of these incidents expand across the Nation. I yield back.

STAFF. Mr. Foster is next.

Mr. FOSTER. Well, thank you, and first, to my colleagues from Texas and to some of our witnesses, I feel your pain, as I too had a daughter and son-in-law trapped in Austin, and living off their automobile battery for days. And I'd like to mention their No. 1 recommendation, which is that everyone in Texas be given at least a rudimentary understanding on how to drive a car on roads after a snow or ice storm. OK, not the subject of our hearing, but an important point.

Now, Mr. Torres and Mr. Jenkins, you mentioned a number of threats to grid reliability, including weather, EMP, wildfires, and others. Many of these can be ameliorated by undergrounding the utilities, an approach which carries multiple secondary benefits like eliminating eyesores, improving real estate property values, you know, preventing wildfires, and so on. So what are the promising directions of Federal R&D into lowering the cost of undergrounding utilities? You know, I'm thinking of, like, swarms of robots that toil away underground to bury utilities, both in urban and rural areas, or just simply lower cost conductor/insulator power conversion strategies for high voltage DC lines, and so on.

You know, are there specific programs that have been defined for—that could absorb increase Federal funding for this research, you know, given that industry is pretty conservative in what it's willing to invest in? You know, what would an underground power transmission moon shot look like? So any one of you want to take a stab at that?

Mr. TORRES. I can't say that I'm an expert on underground DC systems. One of the biggest challenges is the access in the siting to that. There definitely can be further investments to advance the various technologies, to improve on that, to improve on the conductor materials, and so on. There also can be done things at a local level. You know, the—underground lines can, you know, appear at the transmission and distribution level as well. There are places where flooding could be an issue. So you really need to understand where this kind of technology makes sense as well, and if it will actually resolve the issue, and weigh out the costs overall.

But I believe in looking at a portfolio of options, including DC lines, including undergrounding, including microgrids. So I think we're at a point in the evolution of technology, and research, and information here that we have many more possibilities, so I would just caution that we not select just one particular pathway.

Dr. JENKINS. Yeah, maybe just one thing to add for the Committee is to understand that direct current lines are a little bit like the—getting on the highway, where you can only get on and off at certain on and off ramps, and those are the DC—you know, AC to DC converter stations, that we need to hook up these lines to our synchronized AC grid. And there are significant opportunities for innovation in cost reductions in those converter stations which could allow us to make better use of HVDC lines embedded within our broader AC transmission system, so I think that is an area for research that could be, you know, increased funding could go a long way.

Mr. FOSTER. Yeah. Well, if there had been specific plans made for, you know, a program that could absorb significant—larger funding, and, you know, cost production research, basically, because it seems like a big part of that technology has really not changed in the 1960's. And I think, you know, if you look for example, at the cost production in microwaves, you know, we bought a microwave oven, which is, you know, a magnetron in a metal box with a timer, and that's, you know, a drop from $250 of 1960 dollars to about $42 today, you know, not through revolutionary technology, but simply step by step cost reduction, and I think that that's really an area where we could benefit from investment.

And if in a moment I can have an estimate of my time left from the staff, I would—it would be useful.

STAFF. 1 minute, Mr. Foster.

Mr. FOSTER. OK. So many of the really destructive scenarios to the grid, you know, whether they're cyber attacks or accidental, have to do with messing around with synchronizing the phase or frequency of the AC generation and distribution systems. You know, in contrast, DC transport systems, you know, can be protected by relatively simple systems, you know, like diode clamps, over-voltage protection, so on, that don't rely on software that can be corrupted, and can be much more easily made immune to natural and artificial electromagnetic pulse events and so on. Has this been looked at, really, the benefits in terms of disaster resilience, of high voltage—or DC systems generally compared to AC systems?

Dr. TIERNEY. Could I answer very briefly by saying that there has been a lot of research on the technical and regulatory issues associated with HDVC—DC lines. But I think your question and comments really calls out for asking DOE to do a moon shot type road map for that kind of research that would really take things over the hump. As one thinks about the expansion of the system that is going to be required, and the natural resistance that people have to the visual effects of new power lines, I think it is a really important area of work——

Mr. FOSTER. Thank you, my——

Dr. TIERNEY [continuing]. From a scientific basis.

Mr. FOSTER. Thank you. And so I will—happy to collaborate with any of my colleagues on brainstorming what that would look like. And my time is up, and I yield back.

STAFF. Mr. Babin is next.

Mr. BABIN. Yes, sir, thank you so very much. Really appreciate you witnesses being here to talk about something that is so important.

When Winter Storm Uri swept across and through Texas, thousands of my constituents, and millions across the State, found themselves in life and death circumstances, without heat, without water, and access to essential goods, in the coldest storm in modern Texas history. We must address the failures and subsequently support policies that make sure that this catastrophe never happens again. I'd also like to thank Mr. Foster for his suggestion, because many Texans do not know how to drive in these conditions, thankfully, because they're so very rare in the State of Texas.

But our energy sources must be predictable, dependable, and affordable. Unfortunately, the national trend of increasing regulatory policies and green energy subsidies has led to States, in this case Texas, incorporating more unreliable power into the grid while decreasing reliance on proven and dependable base load energy resources. We must recognize the limits of energy sources such as wind and solar. If Texas had been on the grid that was 100 percent renewable, as many continue to advocate for, this weather scenario would have been much worse. Thankfully natural gas, which is a vital contributor to our Texas grid, would carry the lion's share of the load of this energy emergency.

And so, Madam Chair, I ask unanimous consent to submit for the record a one-page fact sheet from the American Exploration and Production Council, which details the role of natural gas during this February's winter event.

Chairwoman JOHNSON. Without objection.

Mr. BABIN. Thank you. So what is the solution? I firmly believe that market-based solutions would better ensure increased grid resiliency. As Pat Woods, previous FERC Chairman, said recently, I can assure you the competitive model is the better way to bring price, service, and technological innovation benefits to the customers.

And so let me also briefly mention that many continue to say the source of the blackouts was Texas's insistence on being part of an independent grid, thus depriving it of ample power from local States and "wise" regulation from the Federal Government. But joining the Federal grid is not the solution, and would have far-reaching consequences, which would include greater market volatility, and much higher prices.

My question to Mr. Garza, if the oil fields have attempted to become more green friendly, they have electrified. Should there be more research and development into microgrids or non-grid electricity? Part of the reason gas couldn't get out of the ground during this storm was because the devices to get it out of the ground simply ran out of electricity. Do you believe that forcing these different types of energy sources to all become electric is the right direction to be heading in?

Ms. GARZA. Well, sir, thank you for your—thank you for that question. Yes, there certainly were situations where gas production and transportation facilities where—which are dependent on electricity found their electricity cutoff. And I would attribute that to a failure of communication, or a failure of understanding by the local distribution utility that they indeed had a critical gas production facility connected to their system. An example that came out during the recent legislative hearings here in Texas is that one of the utilities had about 30 gas facilities on their critical load list before the event, and during the event they identified 130 more. So clearly there's a failure of identification, and, given the interdependence of electricity and gas, the codependence of electricity and gas, we need to figure out a way to improve that communication and coordination.

Mr. BABIN. Thank you, ma'am. And then do you also believe that the current trajectory of research and development funding is doing enough to ensure that we achieve better grid resiliency?

Ms. GARZA. Well, I, you know, I always think there's more to do and more to learn. Clearly we, you know, we failed that test here in Texas, and so we need to learn from those lessons, and we need to figure out how those lessons can be broadly applied to the rest of the country. And, to me, it seems we do that through appropriate research and dissemination.

Dr. TIERNEY. Mr. Babin?

Mr. BABIN. All right, thank you very much, and I think—yes, ma'am?

Dr. TIERNEY. I just wanted to say, clearly the National Academies committees on resilience of the grid and the future of the electric system believe that there needs to be at least a doubling, if not a tripling, of parts of the research chain, so I encourage that to your attention.

Mr. BABIN. OK. Thank you very much, and I see that I'm out of time, so I will yield back. Thank you, Madam Chair.

STAFF. Mr. Kildee is next.

Mr. KILDEE. Thank you. Well, first of all, thanks for holding this hearing. It's obviously an important hearing. I would like to address—and this is something that my colleague from Michigan, Ms. Stevens, raised, and it has to do with the effect of the development of electrication—electrification of transportation of the—of our entire fleet of vehicles over many decades will have on grid resilience, or what factors we need to consider when it comes to that inevitable development. And so I wonder if, Mr. Torres, if you wouldn't mind perhaps reiterating, because I missed part of the answer that you gave—or that was given when Ms. Stevens raised this issue, if you would mind just giving us some of the thoughts that we need to consider regarding grid resilience in the era of obvious development and movement toward electrification of vehicles?

And then I do have an interesting question as to whether or not there's another side to that coin, especially when it comes to heavy duty vehicles, when we think about the fact that, in a case like this, perhaps on a smaller scale, we would have present on the ground, in communities, large—essentially batteries on wheels. Fully charged vehicles, school buses, for example, that might be of some utility in providing temporary relief in the case of, you know, of a blackout of some type. So if you could just touch on those two areas, I'd appreciate it.

Mr. TORRES. Yes, thank you, Mr. Kildee. So what we're seeing in some of the studies I mentioned, early electrification future studies is—there's a high potential for transportation to be a significant new load on the grid, and we see that there would probably need to be some changes on—at the distribution level, when—where we charge, but even charging management systems so not everybody would come home and charge at exactly the same time. Maybe people are charging at night, but you can do it at a different time. So all those kinds of things are definitely achievable with some more research.

With regards to things like vehicles providing support, you know, it's—there's a potential with fleets, with bus fleets, that are maybe only driving certain times, say school buses, but then they sit there most of the day. During that time they could potentially offer some energy to the grid to help support it during time of need. Other, you know, light duty vehicles, we'd need to understand in the future, when you have dynamic generation locations, where are these vehicles, and can they plug in to some, you know, some portal where they could offer some support to the grid? Those kinds of things would still need to be looked at, business models and so on.

But given the fact that, you know, transportation is on a path to at least some level of increased electrification, I think it offers opportunity for us to look at how it can be used to add grid resilience, what are the implications if we don't take into account the growth for light duty and heavy duty vehicles? Light duty vehicles at 150 kilowatt level charging, you know, heavy duty up to a megawatt scale charging, could have large impacts on the grid. At the same time, if we do it wisely, could also potentially add some support.

Dr. RAI. Mr. Kildee, if I may add a couple points? The increasing trend in electrification for transportation highlights one additional interdependence. We already talked about how gas, electricity, and then food and water are connected. We are seeing another, transportation sector, getting—so the interdependencies are going to get more complicated. So that's point one. Second, your observation is absolutely right on. The University of Texas have had demonstration project that have showed that using buses and similar—what you mentioned, storage—you could actually support fire stations and similar infrastructure for certain durations of time, right? You know, not for very long. And the third piece is your comment around large vehicles. That brings an additional element, which is hydrogen. Especially it's very important for Texas, there's a lot of scope there, but it also adds to that diversification of, you know, energy sources, and supply during a, you know, critical time. So, you know, that's a really very promising avenue as well.

Mr. KILDEE. Well, thank you. I appreciate those comments. Only 2 percent right now of American vehicles are electric vehicles, but we know where the market is going, and we actually have this moment in time to prepare for that future, to begin to set the stage for not only greater resilience, but less dependency, and a cleaner environment, so this is a timely hearing. I thank the Chairwoman for raising it, and I particularly thank the panelists for really good testimony. So thank you, and I yield back.

STAFF. Mr. LaTurner is next.

Mr. LATURNER. Thank you, Madam Chair, and Ranking Member Lucas, for holding this hearing, and I want to thank the panelists for being with us. Like many of its neighbors, the State of Kansas was hit hard by the winter storm in February. Subjected to subzero temperatures, many were without power and heat for days. Power and fuel sources that we rely on every day failed, and we weren't prepared. We cannot allow this to happen again. It is my hope that this hearing will shed light on future opportunities to strengthen and fortify our power grid against threats both physical and cyber, and examine how we can leverage our country's research and development capabilities to make those opportunities a reality.

I'd like Mr. Torres and Ms. Garza to address this question. It's a two-part question. How interconnected are the various regional grids? And, while you consider that, the connectivity of the grids, what is the probability that an outage or a cyber event in one part of the country can have a cascading effect on the whole system?

Mr. TORRES. OK, I'll go ahead and go first. Thank you, Mr. LaTurner. So there are only, you know, a small set of DC ties interconnecting the eastern and western interconnect, and then there's also a tie between—I believe there's a Texas and an eastern interconnect. Not a lot of power flows between those systems at this point. They don't really depend on power flows going across. So, at this point, not a lot of dependency, from that perspective.

The—with regards to some of the cybersecurity potential issues here, the potential consequences would depend on the type of event, where the entry was, what system was compromised. The grid is really made up of a whole bunch of small grids, there's a lot of different utilities, so, you know, we're always as—you know, we're as strong as our weakest link, so having some consistency on the expectations in policies, and even technologies and approaches, is really good. I'd say as a whole we're doing a pretty good job at the bulk grid level. NERC has jurisdiction over the larger utilities. You know, they're providing power over the bulk grid, the high voltage level.

Once you get down to the distribution level, you know, they are doing the best they can as well. They are, you know, developing standards and so on, but they don't necessarily have the same level of resources. So finding ways to levelize and provide—given that, you know, potentially a connection anywhere can be a connection everywhere if cybersecurity is not managed appropriately.

There was a—I guess the first power grid outage caused by a cyber attack in 2015 in Ukraine. Could that happen here? Don't know. We've been, you know, in my career I've been looking at this since the 1990's, and the grid has evolved considerably since. I will say that I don't believe that's we're paying attention—enough attention to what the threats are ahead, because we don't know how quickly the cyber threat is evolving. It's evolving very, very quickly, so we need to really move toward more inherently resilient systems, knowing that we don't always know where that next attack is coming from, or even what it might be, but the system would be resilient, be able to isolate and detect something's wrong, and be able to reconstruct, and get the system back up and running as soon as possible.

Mr. LATURNER. I appreciate that. And, Ms. Garza, if you don't mind?

Ms. GARZA. Yeah, sure. From an interconnected standpoint, we've talked about Texas's limited direct current interconnections with the Eastern Interconnect, and a few with Mexico as well. The thing of these different grids is that they are operated synchronously, that is they're moving together, and the DC connection allows that separateness, allows those synchronous operations to be separated.

If—so in this situation, if we had some more connections to the Eastern Interconnect, I'm not sure that that would've been very helpful because all of the regions around us to the north and to the east were suffering their own issues, as you just alluded to in Kansas, and all the way down into Louisiana. The cold weather descended across the center of the country. So incrementally I'm not sure there would've been much opportunity for improvement. If you were talking about sort of national bulk high capacity, the HVDC lines, you know, broadly across the country, yes, that might have been valuable. I'm not sure you could justify that expense just on a winter resilience need in Texas, or more locally, but there are other benefits of that kind of interconnection as well.

Mr. LATURNER. Thank you both very much. I yield back.

STAFF. Mr. Beyer is next.

Mr. BEYER. Thank you very much. I'd like to start with Dr. Jenkins, and—with a sort of foundational existential question, Dr. Jenkins. Now, you're a MIT Ph.D., which I very much respect, so here's the question. We have this feedback loop. We burn fossil fuels, which are amazingly efficient, lots of BTUs concentrated—which leads to climate change and global warming, which leads to extreme events, and then we adapt to this by burning more fossil fuel. Does this make any sense, and is this not the equivalent of smashing your hand with a hammer, noticing that it hurts and is bleeding, so keep hammering harder?

Dr. JENKINS. Well, it's a little bit—and the challenge is a little bit, to use a different metaphor, like trying to build the airplane while flying it, right? So we have to keep our critical infrastructures and our economy going as we transition as quickly and affordably as possible to a cleaner energy system that breaks that link. And so we can't do that overnight, but we can move much faster than we have historically, and that means both greater reliance on variable renewable resources, as well as cleaner firm technologies that can supplant fossil fuels, or could even allow us to continue to use fossil fuels with carbon capture and sequestration.

Mr. BEYER. So, Dr. Jenkins, let me continue on this theme. And I know you're not a regulator, you're a scientist, but Governor Abbott said in a statement yesterday that he'd asked for and accepted the head of the PUC's, the Public Utility Commission's, resignation, and this was after the *Texas Monthly* reported that he had told out of state investors, think Wall Street, on a telephone call that he would work to "throw the weight of the Commission behind stopping calls to reverse billions of dollars in overcharges for wholesale electricity during the storms." It turns out that ERCOT had forgotten to roll back its prices from the sky-high levels as the power came back on. And—independent agency originally thought it was only a $16 billion overcharge. They've dialed it back to $6 billion in overcharges. So, Dr. Jenkins, here's the thought, was ERCOT actually designed to protect ratepayers?

Dr. JENKINS. Well, this is—there's a separate question, I think, is whether the Utility Commission of Texas was, you know, seeing its primary responsibility as to the people of Texas or to the investors in the power system. ERCOT runs the electricity market, but it's regulated by the Utility Commission of Texas, which now has no members, even to figure out how to, you know, navigate after this crisis. So I think it is a shame to see the sort of, you know, vacancy at the Commission now, at a time when we need regulators to be acting on behalf of the public.

Mr. BEYER. Although it is encouraging to see a bipartisan effort to make sure that the ratepayers are protected now, after the fact.

Dr. JENKINS. Yeah.

Mr. BEYER. Dr. Jenkins, would Texas benefit from a capacity market, you know, the so-called forward markets, where we would pay for building capacity, not just for selling electricity?

Dr. JENKINS. I think that's an important and open question. I think, you know, we have to be a little bit careful about thinking about different financial incentives alone as sufficient to ensure weatherization measures. You have to remember that a lot of the generators that went out during this crisis were hedged, so they were actually obligated to pay back the power that they couldn't generate at the market rate of $9,000 a megawatt hour. So they had an enormous incentive to be available, and suffered millions in dollars in losses when they weren't. So I'm not convinced that a capacity market, which would provide different incentives for, you know, for providing firm capacity, would've fundamentally changed those incentives. The financial incentives were pretty strong.

What I think this was was a failure of regulation, honestly, to require certain measures that were cost-effective, and could provide broad public benefits by avoiding these sorts of crises for the, you know, the catastrophic impacts on the public writ large that are much larger than the impacts that any individual power plant would face. So we have a public good here to reliability, and I think that ultimately requires regulation to ensure—the benefit of a capacity market is that it gives you one more point of regulation, where participation in that capacity market, and getting payments, you know, long-term payments for capacity could be contingent on compliance with certain regulations regarding weatherization, and we've seen those kinds of steps taken in other markets, like New England, where they require either firm gas contracts, or dual fuel capacity for, you know, gas plants that can switch over to oil. So that—it would be another point of regulation, but I don't think changing the financial incentives alone would be sufficient.

Mr. BEYER. Would capacity markets have any role in encouraging the diversification of the energy sources?

Dr. JENKINS. Not necessarily. Capacity markets don't necessarily lead to greater diversity. In fact, they primarily benefit natural gas power generators in their current design. We have to think carefully about how we design these long run incentives. They're ostensibly technology neutral, but as Jacob Mays, and Dick O'Neil at FERC, and others have shown, the specific single contract that they offer is well-aligned with the risk profile of gas generators, and other generators face different risks, and so we need more long-term products to address the different risk profiles that they each face in order to ensure more diversity.

Mr. BEYER. Great. Thank you very much. I yield back.

STAFF. Ms. Kim is next.

Ms. KIM. Thank you. Thank you, Ranking Member, and Chairwoman Johnson, for holding this hearing today. You know, unfortunately, my home State of California heavily relies on imported power from other States to help field electricity demand. According to the *Wall Street Journal* article from August 2020, California's grid operator must find 10,000 to 15,000 megawatts replacement power during a period where generation of solar and wind power falls off. The combination of wildfires, and increased demand due to the COVID–19 pandemic, and rising temperatures were a perfect storm, causing power outages in California last summer. And, regrettably, our—as our State looks to purchase more energy from other States and abroad, California plans to shut down the Diablo Canyon power plant at a time when we need a good mix of energy sources.

So I would like to pose the question to all witnesses—grid scale storage will be a key technology driver for security and resiliency as new energy sources are incorporated into the U.S. power grid. So I would like to hear from each of you your perspectives, are there areas of this research that are better off left to the private industry?

Dr. JENKINS. If I could begin, maybe? I think that the history of American innovation around particularly energy technologies is one of active public and private partnership. So the innovation often occurs from private sector businesses, but they're critically supported throughout the entire evolution of that technology by investment on behalf of the public in R&D, in demonstration, in early market opportunities in the forms of procurement, or tax credits, or standards that drive technology. And all of those together help provide the innovative opportunity for the private sector to develop these new technologies. So it's really partnership, and it's one that America excels at, and it's got us cheap wind and solar power, electric vehicle batteries, LEDs (light-emitting diodes), hydraulic fracturing, you know, for—and horizontal drilling, all kinds of technologies that are more than paying off the, you know, the investment that the public has made in those technologies.

Ms. KIM. Great. Anyone want to chime in too?

Dr. TIERNEY. Yes, please. Representative Kim, I'm—I was raised near you, in Redlands, California, and went to school at the Claremont Colleges, so it's—I know your district well. And one of the things that complements what Professor Jenkins just said, with regard to the important role that the Federal Government plays in supporting basic science and applied science on storage, among other things, is the kinds of things that have been done in Southern California to have really a demand pull associated with storage technologies, and moving those into the markets. So those two things in conjunction with each other are really part of the innovation cycle that can pull resources into the market and lower costs over time. So I think there's a lot to learn from California's experience on this.

Ms. KIM. Thank you. I would like to thank Dr. Jenkins and Dr. Tierney for your responses. Let me get onto the second question. How does transitioning to the smart grid, or adding Internet of Things capabilities to industry or control systems influence security and resiliency in the energy sector? How should we think about incorporating new technologies, like artificial intelligence, or the Internet of Things, in developing more efficient battery storage units?

Dr. TIERNEY. We really need to set better standards for assuring grid security protocols related to cyber and other issues, because all of those Internet of Things could have the opportunity to create intrusions into the grid's performance. So there's regulatory in the form of standard-setting that are uniform around the country, but there's really a tremendous amount of R&D that would be subject to your Committee's jurisdiction associated with simulation tools that provide different angles on how there are the interactions between Internet of Things devices and local grid operations. There's a long list of things that I've included in my testimony that would address the kinds of things that you're talking about.

Dr. RAI. If I might add, Ms. Kim, very quickly, there is a flip side to it. As we talked about, smart devices, smart devices, smart meters, could have really helped a lot in terms of very smartly cycling non-critical load, which actually was frozen, and so there were, you know, large parts of the population without power for several days, as well as in terms of predictive capability. You mentioned artificial intelligence. There is a lot of that could be brought to really get a look ahead. And the final point I want to make is, you know, we do want to separate this event from what can be managed through even grid scale storage. You know, this was an event that lasted for 3 days, and, you know, 7 days in many parts. That's, you know, there are very few types of single storage scaled, including, you know, very large—storage that can be brought, but, you know, you can't cite that everywhere, so there are other types of solutions. You know, the scale of this problem is, you know, a little bit on the higher side of the spectrum.

Mr. TORRES. And——

Ms. KIM. Thank you.

Mr. TORRES. —Representative Kim, if I could add something really quickly, maybe to bridge between your two questions? It——

Ms. KIM. Um-hum.

Mr. TORRES [continuing]. Really highlights the importance of government research and government involvement. The industry alone will not have the understanding of the evolving threat, and the national security implications of the work that they're doing. They also tend to focus on more near term research, and so, tying back to the universities, tying to the applied and basic research at the National Laboratories, with the national security in mind, I think is a key as we move forward. Thank you.

Ms. KIM. Thank you. I know my time is up, so I want to thank all the witnesses for your thoughtful responses. Thank you. I yield back.

STAFF. Mrs. Fletcher is next.

Mrs. FLETCHER. Thank you, and thank you to Chairwoman Johnson and Ranking Member Lucas for holding this hearing today. It is incredibly important for those of us in Texas, and for the entire country, to understand what happened, and to craft legislation on this Committee to invest in and encourage research and development in grid technology, and reliable generation technology. I very much appreciate the witnesses sharing their expertise and time with us today, and in written testimony, which has been so helpful.

As one of the Members of this Committee who lived through the Texas winter storm without power for several days, without water for several more, with a boil water notice for many days after that in my district in Houston, I want to underscore the seriousness of these cascading failures in both the physical market and the financial market. Today's hearing is important in making sure that we don't fail to respond in Congress. So many issues have been raised throughout this hearing, and there simply is not time for me to ask all the questions I have in these 5 minutes, so I will submit several questions to the witnesses for the record, and I look forward to your responses.

Like Dr. Rai, I was—the temperatures in my own home were in the 40's, and I think even the 30's, during the event before I found my thermometer, but I was lucky. I had a fireplace, and I had warm clothes. Not very far from my house an 11-year-old boy, who had been overjoyed at seeing his first snow on Monday, froze to death in his own bed overnight. And he was not the only Texan who froze to death in this storm. Others died from carbon monoxide poisoning trying to keep warm. My constituents who are doctors told me they had never seen anything like the number of people they treated for carbon monoxide poisoning during this time.

What we saw in Texas during the winter storm was a catastrophic failure of our electric grid, a catastrophic failure that didn't have to happen. There were ample warnings from both FERC and NERC about how the Texas grid was vulnerable to winter resilience issues that had been documented in detail after the 2011 winter storms. But years of inaction by our State legislature, our Governor, and his appointees at the Public Utility Commission left our State with a grid that focused on market profit at the expense of a resilient grid. While affordable energy should be a key priority of our grid system, Texans saw firsthand the catastrophe that occurs when a grid is unable to function and provide life-saving power when people need it the most.

My colleague, Mr. Bera, recognizing that Texans have a well-known independent streak, mentioned that Texans perhaps choose to pay less than people in California for their energy. But in recent *Wall Street Journal* analysis has found that for two decades Texas customers have paid more for electricity than residents of States served by traditional utilities, $28 billion more since 2004.

Ms. Garza, given your years of experience at ERCOT, I'm interested in hearing your perspective on Texas's failure to plan for peak demand in the winter. And I won't be able to get to all of my questions, but I do want to focus on this because we haven't talked about it in this hearing. It's my understanding that when ERCOT planned for peak demand that would require distributors to shed load, it was done under the assumption that such an event would occur in the summer, when demand is typically highest. When ERCOT ordered distributors to shed load during the storm, the regional allocation for where loads had to be shed was geographically centered around areas where the summer demand would be the highest, particularly in Houston and in South Texas, despite the fact that the north in this case was experiencing higher demand. Is it your understand that this is the case?

Ms. GARZA. Yes, it is.

Mrs. FLETCHER. And do you agree with me that ERCOT should revisit this planning so that it's able to respond better to winter demand events?

Ms. GARZA. Yes, and I think that it's on the list of things to work on. The only thing I would caution you there is that, as you get further south in the State, you—there's more electric heat, and electric heat uses lots of electricity—the inefficient electric heat that generally exists the further south you go. And so—but factoring that in, and understanding a more seasonal distribution of load across the State to more fairly assign those curtailment responsibilities would be an appropriate step, and one that I think is underway.

Mrs. FLETCHER. Well, thank you, Ms. Garza. With my last few seconds I just want to mention, and ask this question, in your written testimony, and in your opening comments today, you mentioned that in setting standards we should have benefits that exceed costs, and noted the infrequency of cold weather in Texas is part of that analysis. With the deaths of at least 70 Texans, the illnesses of many more, with tens of billions of dollars in damages to people's homes and businesses across the State, my question is whose costs are you referring to in your analysis? And, unfortunately, I'm out of time, so I'll take your response in—written response, but I really appreciate all of you being here today, and, Madam Chairwoman, I yield back.

STAFF. Mr. Gonzalez is next.

Mr. GONZALEZ. Thank you, Chairwoman Johnson and Ranking Member Lucas, for holding this timely hearing today, and our distinguished witnesses for joining us. One thing I like about the Science Committee is we actually talk about facts, unlike the narratives that I see coming out on social media. In one case, when I flipped on my social media, which I'm one not to do, folks on the right saw it as the Texas blackouts, which were tragic, as justification for criticisms of wind turbines, and renewable energy generally. On the left, those opposed to federalism—free market ideas criticized Texas's deregulated energy market because some companies to prioritize cost over safety.

Of course, the answer is both charges are true, partially. Power generation companies in Texas took a market risk and chose not to harden their facilities. I think we highlighted that today. And given the high variance of wind and solar, relying on renewables as a primary source of energy increases costs to consumers, can export jobs, and weakens energy independence. What we need is a system that works both ways. Renewable energy serves a purpose when it correctly supplements higher density energy sources. As cheaper, more effective technologies come online, they absolutely should be deployed. And, given the threat of uncontrollable weather events, Texas's power generators and utilities should be encouraged to winterize their facilities, and toughen the grid against extreme stress.

We should also reconsider our approach to nuclear energy, which is a big priority of mine on this Committee, and across this Congress. While nat gas, coal, and renewable energy capacity plummeted during the blackouts, nuclear remained relatively reliable, operating at 74 percent of total capacity. I want to start with that fact specifically, and Dr. Jenkins. What is it about nuclear that allowed it to do better relatively? I know it too suffered, but relative to the other energy sources, is there something inherent to the technology, or is it coincidental? Just kind of walk me through what it is about nuclear that allowed it to be a little bit more resilient through the Texas cyclone.

Dr. JENKINS. I mean, the main benefit that nuclear enjoys over natural gas in particular is it doesn't need fuel delivery during these kinds of events, and so it's one less vulnerability to supply disruptions on the fuel side of things. You know, the—these—because of the focus on safety and reliability in the nuclear power fleet as well, there are considerable efforts and investments made in maintaining the highest degree of reliability for those plants, and so they also tend to perform better during these sorts of extreme events as well because they are, you know, they're considerably, and justifiably, focused on maintaining the highest reliability.

I think what the performance of the nuclear fleet also shows is that the diversity of resources helps decorrelate the failures, right? If you have 10 power plants that all have a 10 percent chance of failure, but those aren't at all related to each other, the odds of them all failing at once are, like, 10 to the negative ninth, you know, percent. It's, you know, infinitesimally small. But if they're all linked up to the same natural gas system, and that system goes down, or they're all in the same part of the transmission grid, and that transmission grid fails, then, their outages are correlated, and so I think we have to think carefully about how we diversity the risk exposure. And nuclear has its own risks, but, you know, there are different—they're different than those for other power sources, and that improves the resilience of our system through diversity.

Mr. GONZALEZ. Thank you. And, in your opinion, what do you think the appropriate role for nuclear is when it comes to generation, and our goals around reducing our carbon footprint?

Dr. JENKINS. Well, I think there's two things to note. The first is that our existing nuclear power fleet is by far the cheapest source of clean firm generation capacity that we could have. Any new source of carbon-free firm generation is going to be more expensive, with rare exceptions, than maintaining our existing nuclear fleet as long as it is safe to operate. So that's the foundation upon which we can build toward a lower carbon and cleaner energy system. And then, in the future, newer nuclear power plants are one of several types of clean firm generation technologies. At the moment none are licensed for sale, right? We need to see——

Mr. GONZALEZ. Yeah.

Dr. JENKINS [continuing]. The NRC (Nuclear Regulatory Commission) process through for the new scale reactors, for the GE-Hitachi BWR-X, for the others that are moving their way through the process, and when they come to market, we'll be able to see if they can compete with other clean firm generation technologies, like advanced geothermal, or Allam cycle power plants, or natural gas power plants with carbon capture, biomass gasification, hydrogen turbines. There's a whole range of options, and all of those are in a more nascent state today than other technologies, and so I think the race is on, and the efforts that this Committee has made in the *Energy Act*, and other legislation, to support the development of those technologies will help propel them forward.

Mr. GONZALEZ. So fair to say, in your estimation, nuclear should play an important role in our energy generation future in the United States?

Dr. JENKINS. Yeah. I think it already plays an important role today, and it can sustain that role into the future as well, especially if the new technologies can be affordably built, and on time, with little risk, which has been the challenge so far for the nuclear fleet.

Mr. GONZALEZ. Thank you. I hope everyone was listening. I yield back.

STAFF. Mr. Perlmutter is next.

Mr. PERLMUTTER. Thank you very much to our Chairwoman and to the Ranking Member for this panel. You guys are great, it's—and you've got a lot of stamina to answer all these questions for this long. I've got a couple, one for the panel generally. And one of the reasons that I've lasted this long is that there's a Coloradan on the panel, and so I want to start with him.

Mr. Torres, you know, you've talked about microgrids a lot. Explain to me, and to us, you know, how a microgrid, you know, has helped with the California wildfires, how it could help with the wildfires that we face in Colorado from time to time. Let's start with that question. And then I have a general question to the whole panel. You can think about it. We're going to do an infrastructure bill, a big one, that's going to be loads of bridges, and waterworks, and broadband, but there's going to be an emphasis on the electrical grid. If all of you could think of a couple things you'd like to see us do, either regionally or nationally, to upgrade the grid? So—but I'd like to start with you, Mr. Torres.

Mr. TORRES. Thank you, Representative Perlmutter. So first maybe understand—we should get on the same page about what I'm referring to as a microgrid. A microgrid is a smaller grid tied to the bigger grid that can disconnect and reconnect as needed. And why would you want to do that? And there are some really good examples with regards to even the recent wildfires in California. Borrego Springs is a microgrid demonstration. We've been working with them for quite a while. They have a lot of issues with transmission line, and the lack of reliability at times for them. So they needed ways to make sure that we could—they could keep the local power up and running. With some local sources, you can use a variety of generation sources. Renewable solar, different types of gen sets, energy storage, and so on.

We're seeing the trend for those kinds of organizations that have a high necessity for very, very reliable power. For example, military installations have been working this space for a long time, and there was a big demonstration I was involved in about 10 years ago called the Spiders demonstration with—between the military and the Department of Energy. There are also other, you know, resources—or, I'm sorry, other loads that really need high reliability power. For example, data centers. They need to increase the amount of reliability because some of the computer systems are very, very sensitive to power.

So I believe in the future we're going to see a lot more owners and operators of various loads that will want to make sure that, if there's a loss of a transmission line, or loss of centralized generation, that they can still operate through. So I foresee—microgrids would be an important element of the future evolving grid.

Mr. PERLMUTTER. Thank you. So, Dr. Tierney, let's go to you, and——

Dr. TIERNEY. Well, thank you, because——

Mr. PERLMUTTER. Yes.

Dr. TIERNEY [continuing]. I live in Colorado, so you have a second Coloradan on this panel.

Mr. PERLMUTTER. Well, let's go to you, and if you want to talk about microgrids, or how you think, as a general principle, we can upgrade the system.

Dr. TIERNEY. Yeah, OK.

Mr. PERLMUTTER. Give me a couple examples.

Dr. TIERNEY. Well, and I'm going to talk about it in the context of a clean infrastructure recovery package, if that's OK. So I——

Mr. PERLMUTTER. Sure.

Dr. TIERNEY [continuing]. Think there could be elements associated with infusing more dollars into building energy efficiency. So boring that sounds, but what a difference that would make if buildings were buttoned up so that houses that were facing either extreme cold or hot events were much more able to withstand those kinds of outside temperatures. Especially doing that in low income areas, and bundling those two things together, would be very important.

Second, there is a green bank that is now included—I think it's in the *Clean Futures Act*. It's the accelerator, Clean Energy Accelerator. It would be a multi-multi-billion dollar infusion of support for local investments that deal both with lowering greenhouse gas emissions with various types of projects, as well as equity considerations. Another, third, issue is tree planting in urban areas, where there are real hot spots. And tree planting in Colorado would not be a bad idea as well, just to restock the forests. Transmission investment, we've already talked about, and then finally, in your jurisdictional authority area, all of these investments in R&D for grid resiliency at various stages in the process, and to harden the grid, and deal with cyber security, they're ripe for inclusion in this package. How's that?

Mr. PERLMUTTER. Thank you very much, and I want to thank the entire panel. I can't get to all of you, but I want to especially thank the Coloradans.

STAFF. Mr. Baird is next.

Mr. BAIRD. Thank you. Madam Chair, and Ranking Member Lucas, I really appreciate your cooperation in bringing this kind of timely Science Committee meetings, and then to have the talent and capabilities of our witnesses, is very much appreciated. I always learn something.

We're interested in research, research and development, and it's a recurring trend, I think, in the industry, per se, across the country about the need for government, and academia, as well as private industry, to work together so that we can continue to be successful and be a leader around the world using American technology. So the National Labs, I've been impressed with those, and the things that they do, and I think it's important that we focus on the kinds of research that you think are necessary. So I'm going to start with Mr. Rai.

Dr. Rai, what do you think is the difference between academia research and private industry research? Are there priorities? Can you help prioritize where you think we need to go focusing on that research?

Dr. RAI. Thank you for that question, Mr. Baird. One of the key things that academic research is—that it is long range, and more basic—as we heard earlier in this hearing, that typically the private industry also does a lot of research, but that's really much harder—year to, you know, 5 years, and rarely it is, you know, out—10 years out. But a lot of the question that you're talking about, not of the research that can be done, really is—benefit in the long run. We heard about many computing technologies, about hydraulic fracturing, about storage technologies, wind and solar, these took a long view, lot of investment over multiple decades, and then supported demand for policy as—and so, you know, there's really this sequencing—there's a lot of interaction, but still there's a sequencing in terms of both the nature of the problem, which are more fundamental, as well as the time horizon that the academic research really depreciates itself, but it has a very fundamental place, in terms of generating that diversity of powerful ideas that can then really play out in the—over time.

Mr. BAIRD. Thank you. Would you agree with the idea that private industry can't really justify just basic research, whereas academia, we invest in that basic research, and we still get a return at some point down the road? It may not look like important research at the moment, but down the road private industry kind of picks that up. Is that—have I got an appropriate analysis of that situation or not?

Dr. RAI. Absolutely, sir. It has played out again and again in very big ways—in very radical big ways that change the world forever in multiple sentences. So, yes, sir.

Dr. JENKINS. Congressman, if I could just add to that, the partnership between universities and National Laboratories also extends beyond the basic research. There's applied research programs carried out in partnership with industry that continue to provide critical incremental innovations that move these technologies along and make American technological companies—technology companies, you know, maintain their competitive edge as well. So it extends into that translational and applied research realm also.

Dr. TIERNEY. And especially because some of this grid resiliency R&D is really a public good, and no private company can really monetize its investment in R&D for such a broad-based thing. We really do need R&D in this area federally funded.

Mr. TORRES. Yeah, if I could add something as well, I think that partnership across academia, where they could focus on longer term research, basic research, higher risk, where industry cannot. They need to have a return, something that's a little bit more certain, with lower risk, and the laboratories kind of cover that spectrum. One of the roles that we have here at NREL is providing that bridge, taking, you know, the basic and applied research, and working with industry, going from, hey, can we prove this in a laboratory, but can this—to the next level, can we actually deploy it? How would it deploy, and can we minimize the risk before it gets deployed in full scale?

Mr. BAIRD. Thank you. Ms. Garza, you got any comment?

Ms. GARZA. So my—no. Short answer is no.

Dr. JENKINS. Could I just maybe add that I just strongly encourage the Committee to work with your colleagues to ensure appropriations that fulfill the kinds of authorizations included in the *Energy Act*? You've made enormous, you know, focus on the kinds of innovative priorities that we have, and we're talking about here, but unless the budget comes through, it's not going to be something that the labs, and universities, and private sector can tackle.

Mr. BAIRD. Well, thank all of you for being here, and I see I'm out of time, so the Chair will probably cut me off right quick. Thank you.

STAFF. Ms. Ross is recognized next.

Ms. ROSS. Thank you so much, and thank you, Madam Chairwoman, for having this important hearing, and in such a timely way. I—I'm from North Carolina, and we are no stranger to odd weather, hurricanes. Today tornadoes are predicted in my district, and having a resilient energy grid, and a modern energy grid, is so, so important to not just delivering the energy every day, but dealing with these severe weather incidents.

My first question is to Ms. Garza. In your testimony you speak about the need for better long-term forecasting of potential conditions. And, as I said, North Carolina's no stranger to severe weather, including severe winter weather. As a matter of fact, we—in our integrated resource planning, winter peaking has replaced summer peaking because of severe winter weather. I don't know if you knew that about North Carolina, but it was a surprise to a lot of people. We have tropical storms, hurricanes, flooding, and—so this can happen year-round. Could you please elaborate on how improved forecasting could help utility companies, State and local authorities, and consumers prepare for extreme weather events, like the one that happened in Texas, and happens frequently in North Carolina?

Ms. GARZA. Sure. You know, as I've mentioned, the, you know, the typical pattern has been to just look back at, well, how bad has the weather been, and let's assume that that's as bad as it's—it will be, and with additional population, additional uses, what will my demand for electricity be? And clearly that was insufficient here in Texas. One of the reasons for that look back would be for States like yours, in North Carolina, that are regulated, and they have to justify those expenses. It's easy to justify, well, I'm going to build for this, because we know it's happened. And unless there's additional input that says, well, the risk is larger than what you've actually occurred, I could see where it would be difficult for utilities that are reliant on rate-based recovery, or, you know, regulated rates of return, to justify additional expenditures. So that's another reason, another justification, for outside help, you know, input into the electric utility to make sure that they're adequately planning for the long term, whether it's heat, or cold, or storms, or whatever.

Dr. JENKINS. Yeah, and Congressman, this is——

Dr. TIERNEY [continuing]. I add to that, please? Because forecasting, and R&D in support of much finer forecasting, has this long-term component for demand, and it should take into consideration changes in the climate for sure. But there are short term operational forecasting issues where integration between wind forecasts and local effects, heat forecasts in certain areas, demand forecasts on a couple of days ahead. Those—and the forecast of outage probabilities of facilities under different kinds of climate events. Those kinds of things—that's a really important R&D—for resilience.

Ms. ROSS. Thank you——

Dr. JENKINS. And as I——

Ms. ROSS [continuing]. Very, very much. Yes?

Dr. JENKINS. Sorry——

Ms. ROSS. Somebody else want to jump in?

Dr. JENKINS. Yeah. Sorry to interrupt. As I emphasize in my testimony as well, I do think that additional climate science investment that focuses on this question of how these extreme weather events and threats are changing, you know, the probability distribution is moving, and it's those tail events that are the big threats to our system, and so those just get a little bit more likely. That has huge implications for how we plan and prepare our systems, and we need the forward-looking science to be able to help guide us as the climate changes over the next several decades.

Ms. ROSS. Thank you, Dr. Jenkins. My next question is for you. We—North Carolina's currently No. 2 in solar in the country, and—so we're interested in clean firm energy. I've represented solar companies, and actually connecting to the grid sometimes is the thing that keeps them from being able to realize their projects. You argue that we don't need every source of electricity to be reliable all the time, we just need the overall system to be reliable. In our last 23 seconds, could you just discuss further how we might be able to do that with an improved grid?

Dr. JENKINS. Well, I think the critical need is for technologies that can replace, ultimately, our natural gas fleet, and our retiring coal, and eventually nuclear power plants that can provide a similar role as those power plants play today, but without the carbon dioxide emissions and air pollution associated with fossil generation today. So that could be advanced nuclear, natural gas plants with carbon capture and storage, advanced geothermal technologies. That could be potentially be very low cost, very long duration energy storage, although those typically are only a partial complement or substitute, and potentially hydrogen production, which could come from renewable sources, could come from biomass, and it could come from natural gas with carbon capture, all of which would provide a zero carbon fuel that could be used in converted natural gas power plants in the longer run.

So all of those are options, and I think, again, as I mentioned earlier, the race is on between them to see which will be developed and scalable, and I think we need a diversity of those technologies because what works in North Carolina may not be what works in Texas, or in Minnesota, or in New England. And so we need a mix of resources that can play that role, the right, you know, role in each parts of the country.

Ms. ROSS. Thank you, Madam Chair, and I yield back.

STAFF. Ms. Bonamici is next.

Ms. BONAMICI. —Member Lucas, and thank you to our witnesses for joining us today. I regret I couldn't be in the entire hearing, but I care a lot about this very important topic. And we know that as we transition to a 100 percent clean energy economy our electric grid will be a central feature of a comprehensive climate strategy. Our grid needs to be clean, reliable, and, importantly, resilient to climate threats.

According to a recent report from the University of California Berkeley an infrastructure build out needed to achieve a 90 percent carbon would support approximately 550,000 jobs each year, and avoid at least $1.2 trillion in cumulative health and environmental challenges. Last—I joined my colleagues on the Select Committee on the Climate Crisis in releasing a bold, comprehensive, science-based climate action plan reaching net zero emissions no later than mid-century, and net negative thereafter. Our plan includes many recommendations on grid resilience, including Congressman Bera's bill, which I know we're focusing on today.

According to a report from the Government Accountability Office, GAO, released just last week, the climate crisis could affect every aspect of the grid, from generation, transmission, and distribution to demand for electricity, and cost billions of dollars annually. GAO specifically found that the Department of Energy does not have a strategy, goals, objectives, or performance measures to guide its efforts to enhance the resilience of the grid—climate crisis. And this is of particular concern to Oregonians in my State because of our raging wildfire season and other reasons as well.

So, Dr. Tierney, how can the DOE best work with Federal science agencies to better understand, predict, and respond to grid threats from the climate——

Dr. TIERNEY. There are dozens of things that the Department of Energy should be doing, and I think there is a groundswell of support for becoming more aggressive on resiliency issues. There was a wonderful program called the Grid Modernization Program that was authorized for 5 years, I think, Juan? Is that right? And continuing and depending that kind of work, supported—supporting work at the labs, will be extremely important on these issues.

But also, as you say, standard setting for performance is badly needed. It's a tough area, when you think about those different levels of the system, generation, transmission, distribution, and demand, but hard work needs to be done there. Thank you for the question.

Ms. BONAMICI. Thank you. And following up on Representative Ross's question, Dr. Jenkins, I appreciated the reference in your testimony to not needing every source of electricity be—to be reliable all the time, and instead focusing on the system, that requires a mix of electricity resources, all playing the right role on the electricity team—isn't—important that we think about equitable access to—affordable clean energy so you can discuss the opportunities to make our transition to a 100 percent clean energy reliable and resistant grid equitable for vulnerable communities who have been on the front lines of the climate crisis?

Dr. JENKINS. Well, I think that the—first I should add, Representative Bonamici, I was born and raised in your district, so it's a pleasure——

Ms. BONAMICI. I'm honored.

Dr. JENKINS [continuing]. To talk with you. I think that there are huge benefits—potential benefits to a transition to a cleaner energy system for all communities, including those that are currently suffering the most from air pollution from our current fossil energy mix. You referenced a Berkeley Labs study on the 90 percent reductions in—or 90 percent clean by 2035 power system. I'd refer you to the Net Zero America study that we worked out of Princeton as well, which estimates very similar benefits for—in terms of reduced air pollution, particularly from the phaseout of our coal fired power plants, which Oregon is scheduled to retire its last coal fired power plant later this—in a couple years, and this could result in—that, and electrification of vehicles, which are the major source of urban air pollution, could substantially reduce exposure to air pollution, and save significant lives and costs for households and communities.

The other thing we have to think carefully about is where we want to direct investment in the new industries that are growing to deploy, you know, clean energy, and to manufacture the products there, and to ensure that those are distributed across our country in ways that communities in transition benefit from. And Oregon knows very keenly the challenges of a large-scale transition. I grew up in the aftermath of the timber wars, and the, you know, the impacts that the phase-out of the timber industry had across Oregon communities, and I think we need to make sure that we're proactively investing in economic development and diversification in communities that are currently relying on fossil generation or fossil fuel production as part of this.

Ms. BONAMICI. Thank you, Dr. Jenkins. I'm working on a national transition legislation, so we really do absolutely need to focus on those front-line communities. I also want to mention too, because you're an Oregonian, that we're doing some really exciting work on marine energy——

Dr. JENKINS. Um-hum.

Ms. BONAMICI [continuing]. Off the coast because, unlike the sun and the wind, the waves are constant, so there's a tremendous amount of potential to capture the power of the waves, tides, currents. So——

Dr. JENKINS. Yeah, as—along with floating offshore wind turbines, which could open up a huge—I mean, the West Coast has the windiest, you know, highest wind potential in the country, if we could cost-effectively tap into it.

Ms. BONAMICI. Well I'm, of course, working in collaboration with all our coastal partners. There's—tremendous amount of potential. Thank you very much, Madam Chair. I yield back.

STAFF. Chairwoman Johnson, all the Members present have been recognized already, so I think we're ready to close out the hearing.

Chairwoman JOHNSON. Thank you very much to all of our tremendous witnesses. We are delighted that you had the time to spend with us, and I'll thank all of our Members for participating. Before we bring the hearing to a close, I would just simply like to say to our witnesses to stay close. We might have some questions that you might receive, and we really, really, really appreciate your input.

The record will remain open for at least 2 weeks for additional statements from the Members, or to submit questions for our witnesses. And—so now I'll—whatever questions that our Committee Members might ask witnesses. Our witnesses now are excused, and our hearing is adjourned.

[Whereupon, at 12:57 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Jesse Jenkins

U.S. HOUSE OF REPRESENTATIVES COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

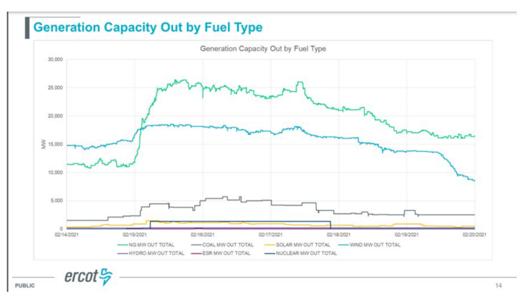
"*Lessons Learned from the Texas Blackouts: Research Needs for a Secure and Resilient Grid*"

Response to Questions for the Record to:
Dr. Jesses Jenkins
Assistant Professor of Mechanical and Aerospace Engineering Andlinger Center for Energy and the Environment at Princeton University **Submitted by Representative Charlie Crist**

1. As you alluded to in your testimony, some have placed the blame for what happened in Texas during the winter storm squarely on renewable energy, particularly wind energy. While I'm aware that all energy sources faced challenges during the storm, it's my understanding that renewables performed much closer to expectations than coal or gas. And that coal and gas may have actually *under*performed ERCOT's most extreme forecasts. Can you discuss the performance of renewables during the winter storm as compared to expectations? As well as discuss the performance of renewables compared to fossil fuels like coal and gas?

ERCOT conducts an annual winter Seasonal Assessment of Resource Adequacy report (SARA) in which they consider the expected availability of all resources and ensure they have adequate firm capacity to make it through both expected and 'extreme' winter scenarios. The most recent Winter 2020/2021 report is available at http://www.ercot.com/content/wcm/lists/197378/SARA-FinalWinter2020-2021.pdf.

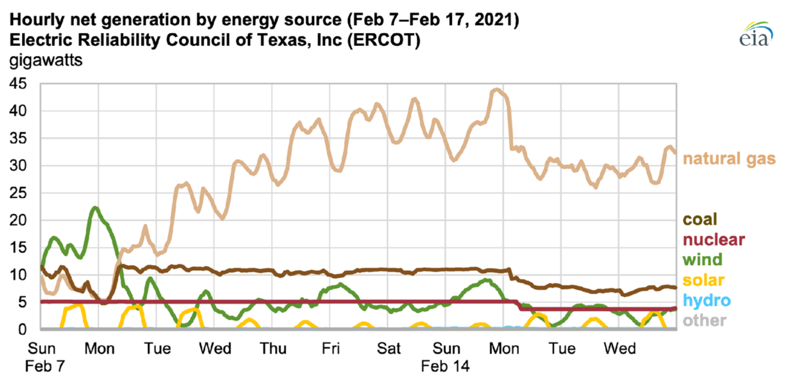
This report notes that ERCOT has 67,529 MW of thermal and hydro capacity, plus another 7,341 MW of 'switchable' resources that can be made available to ERCOT during winter peak events. Of this total 74,870 MW of non-wind and solar capacity, ERCOT expects 4,074 MW to be out on scheduled seasonal maintenance outages during a normal winter, and another 4,542-5,339 MW on forced outages. In extreme scenarios to gauge resilience to risks, the SARA report also considers a "95th Percentile Forced Outages, Thermal" scenario in which another 4,540 MW is offline due to forced outages. So ERCOT plans to their system to be resilient to as much as 13,953 MW of thermal plant outages.



During the period from February 15-18th, ERCOT had more than 25,000 MW of thermal capacity offline, or about 11,000 MW more than the worst case extreme scenarios for which ERCOT planned. See http://www.ercot.com/content/wcm/key_documents_lists/225373/2.2_REVISED_ERCOT_Presentation.pdf

The SARA report also notes that ERCOT counts on an average capacity contribution of 7,070 MW of wind resources, calculated based on the assumption that 43% of installed coastal wind capacity, 32% of Panhandle wind capacity, and 19% of other wind capacity is available during an average winter peak event. Another 269 MW of solar is estimated for average winter events, based on 7% of maximum solar capacity. In extreme scenarios, SARA also considers a low wind period with 5,279 MW less wind capacity available, meaning that ERCOT was planning their system to be resilient to as little as 1,791 MW of wind output was counted on (and presumably zero solar output).

The actual performance of wind throughout the February 15-17 period was generally above the minimum ERCOT scenario of 1,791, but below the average scenario of 7,070 MW (see EIA here https://www.eia.gov/todayinenergy/detail.php?id=46836). Wind output dipped as low as a few hundred MWs for a couple of hours during February 16th and 17th, so during these periods, wind fell about 1500 MW short of the extreme low wind scenario ERCOT had planned for. Solar output ranged from 0 at night to as much as 4 GW during daytime hours.



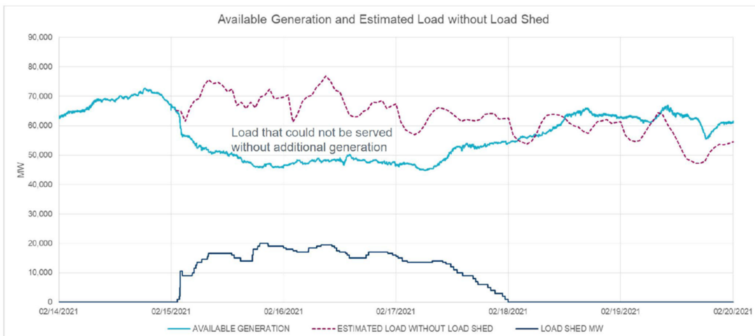
Source: U.S. Energy Information Administration, Hourly Electric Grid Monitor (ERCOT net generation by energy source)

In summary:

- Thermal plant outages were around 25,000 MW, exceeding the ERCOT winter extreme outage scenario of 13,953 MW by about 11,000 MW, and the average winter peak load event outage rate of 9,413 MW by about 15,600 MW. These outages persisted for 2.5 days
- Wind output at its lowest was about 1,500 MW below the ERCOT winter extreme low wind scenario and about 6,800 MW below the average winter peak availability assumptions. This level of low wind output persisted for a couple of hours at a time. Wind output was generally about 5,000 MW during the period, or 3,500 above the extreme low scenario and 2,000 MW below the average winter availability scenario.

- For context, ERCOT estimates that total demand would have been as high as about 76,000 MW without load shedding, or 9,000 MW above the extreme peak load scenario of about 67,208 MW considered by ERCOT, based on the March 2011 winter storm.

Available Generation and Estimated Load Without Load Shed



Available Generation shown is the total HSL of Online Resources, including Quick Starts in OFFQS. The total uses the current MW for Resources in Start-up, Shut-Down, and ONTEST.

PUBLIC ercot 15

Seasonal Assessment of Resource Adequacy for the ERCOT Region
Winter 2020/21 - Final
Release Date: Novermber 5, 2020

Forecasted Capacity and Demand

Operational Resources (thermal and hydro), MW	67,529	Based on current Seasonal Maximum Sustainable Limits reported through the unit registration process
Switchable Capacity Total, MW	3,710	Installed capacity of units that can interconnect with other Regions and are available to ERCOT
Less Switchable Capacity Unavailable to ERCOT, MW	-568	Based on survey responses of Switchable Resource owners
Available Mothballed Capacity, MW	0	Based on seasonal Mothball units plus Probability of Return responses of Mothball Resource owners
Capacity from Private Use Networks, MW	3,631	Average grid injection during the top 20 winter peak load hours over the last three years, plus the forecasted net change in generation capacity available to the ERCOT grid pursuant to Nodal Protocol Section 10.3.2.4.
Coastal Wind, Peak Average Capacity Contribution, MW	1,480	Based on 43% of installed capacity for coastal wind resources (winter season) per ERCOT Nodal Protocols Section 3.2.6.2.2
Panhandle Wind, Peak Average Capacity Contribution, MW	1,411	Based on 32% of installed capacity for panhandle wind resources (winter season) per ERCOT Nodal Protocols Section 3.2.6.2.2
Other Wind, Peak Average Capacity Contribution, MW	3,251	Based on 19% of installed capacity for other wind resources (winter season) per ERCOT Nodal Protocols Section 3.2.6.2.2
Solar Utility-Scale, Peak Average Capacity Contribution, MW	269	Based on 7% of rated capacity for solar resources (winter season) per Nodal Protocols Section 3.2.6.2.2
Storage, Peak Average Capacity Contribution, MW	0	Based on 0% of rated capacity (winter) season); resources assumed to provide regulation reserves rather than sustained capacity available to meet peak loads
RMR Capacity to be under Contract	0	
Capacity Pending Retirement, MW	0	Announced retired capacity that is undergoing ERCOT grid reliability reviews pursuant to Nodal Protocol Section 3.14.1.2
Non-Synchronous Ties, Capacity Contribution, MW	838	Based on net imports during winter 2013/2014 Energy Emergency Alert (EEA) intervals
Planned Thermal Resources with Signed IA, Air Permits and Water Rights, MW	0	Based on in-service dates provided by developers
Planned Coastal Wind with Signed IA, Peak Average Capacity Contribution, MW	371	Based on in-service dates provided by developers and 43% winter capacity contribution for coastal wind resources
Planned Panhandle Wind with Signed IA, Peak Average Capacity Contribution, MW	0	Based on in-service dates provided by developers and 32% winter capacity contribution for panhandle wind resources
Planned Other Wind with Signed IA, Peak Average Capacity Contribution, MW	557	Based on in-service dates provided by developers and 19% winter capacity contribution for other wind resources
Planned Solar Utility-Scale, Peak Average Capacity Contribution, MW	35	Based on in-service dates provided by developers and 7% winter capacity contribution for solar resources
Planned Storage, Peak Average Capacity Contribution, MW	0	Based on in-service dates provided by developers and 0% winter capacity contribution for storage resources
[a] Total Resources, MW	82,513	
[b] Peak Demand, MW	57,699	Based on average weather conditions at the time of the winter peak demand from 2004 – 2018, and updated to reflect a revised economic growth forecast prepared in April 2020
[c] Reserve Capacity [a - b], MW	24,814	

Range of Potential Risks

	Forecasted Season Peak Load	Extreme Peak Load / Typical Generation Outages During Extreme Peak Load	Forecasted Season Peak Load / Extreme Low Wind Output	Extreme Peak Load / Extreme Generation Outages During Extreme Peak Load	
Seasonal Load Adjustment	-	9,509	-	9,509	Based on the 2011 winter and a revised economic growth forecast prepared in April 2020 ; the extreme winter forecast is 67,208 MW
Typical Maintenance Outages, Thermal	4,074	4,074	4,074	4,074	Based on the historical average of planned outages for December through February weekdays, hours ending 7 am - 10 am, for the last three winter seasons (2017/18, 2018/19, and 2019/20)
Typical Forced Outages, Thermal	4,542	5,339	4,542	5,339	Based on historical average of forced outages for December through February weekdays, hours ending 7 am - 10 am, for the last three winter seasons (2017/18, 2018/19, and 2019/20); both Extreme Load scenarios include typical fuel limitation-related derates/outages at units in north Texas during extreme peak load hours
95th Percentile Forced Outages, Thermal	-	-	-	4,540	Based on the 95th percentile historical average of forced outages for December through February weekdays, hours ending 7 am - 10 am, for the last three winter seasons (2017/18, 2018/19, and 2019/20) plus additional fuel limitation-related derates/outages at units in north Texas during the peak load hours for the January 17, 2018 cold weather event
Low Wind Output Adjustment	-	-	5,279	-	Based on the 5th percentile of hourly wind capacity factors (output as a percentage of installed capacity) associated with the 100 highest Net Load hours (Load minus wind output) for the 2015/16-2019/20 winter Peak Load seasons; this low wind output level is 1,791 MW
[d] Total Uses of Reserve Capacity	8,616	18,922	13,895	23,462	
[e] Capacity Available for Operating Reserves, Normal Operating Conditions (c-d), MW	16,198	5,892	10,919	1,352	See the Background tab for additional details

2. Is it fair to say that renewable energy is not the sole - or even the main - reason the Texas grid nearly failed during the storm?

Correct. If we summarize the information above, we can see that total load shedding was as high as ~20,000 MW, of which we can roughly attribute ~9,000 MW to higher than forecasted demand, ~11,000 MW to thermal plant forced outages, and no more than ~1,500 MW to wind outages/low wind availability, relative to the extreme scenarios ERCOT plans for.

Renewable energy outages thus constitute the smallest contributor to total load shedding during the crisis.

3. Do you think expanding the deployment of renewable energy and energy storage would contribute to making the grid more resilient? Why or why not?

I do not think that expanded wind and solar capacity would make the ERCOT grid more resilient to extreme weather events like this, nor would it make it *less* resilient. The key as I noted in my testimony is to ensure adequate firm generating capacity remains in the system, *and* that such resources are *actually firm*: meaning available to generate when we need them. When firm resources fail to materialize, that's when grids fail.

Responses by Dr. Sue Tierney

Testimony of Susan F. Tierney, Ph.D.
Senior Advisor, Analysis Group, Inc., Denver, Colorado

Before the U.S. House Committee on Science, Space and Technology Committee

Hearing on
"Lessons learned from the Texas blackouts: Research needs for a secure and resilient grid"
March 18, 2021

Response to Questions for the Record

Submitted by Representative Charlie Crist

Given that Texas saw challenges across all types of energy sources, it's clear that more must be done to prepare our grid and energy infrastructure for severe weather events. Do you think there should be more stringent weatherization requirements for critical grid and power generation equipment? Why or why not?

Response by Dr. Susan Tierney

The owners and operators of electric grid assets (as well as other energy infrastructure) should assume that the availability and performance of their equipment will be subjected to extreme weather conditions in the future. Such owners and operators should plan to mitigate risks to performance and operations, including through weatherization investments. Requirements and/or incentives for weatherization measures could come from some combination of actions by legislators, state utility regulators, reliability entities, insurance companies, and electric company management.

Note that the scientific evidence is clear that different regions of the U.S. will experience more erratic and uncertain extreme weather events. For example, the 2018 National Climate Assessment made the following findings with respect to energy and other infrastructure.

> "The Nation's energy system is already affected by extreme weather events, and due to climate change, it is projected to be increasingly threatened by more frequent and longer-lasting power outages affecting critical energy infrastructure and creating fuel availability and demand imbalances. The reliability, security, and resilience of the energy system underpin virtually every sector of the U.S. economy. Cascading impacts on other critical sectors could affection economic and national security."
>
> > (Zamuda, C., D.E. Bilello, G. Conzelmann, E. Mecray, A. Satsangi, V. Tidwell, and B.J. Walker, 2018: Energy Supply, Delivery and Demand. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)] U.S. Global Change Research Program, Washington, DC, p. 175. https://nca2018.globalchange.gov/chapter/energy)
>
> "Climate change and extreme weather events are expected to increasingly disrupt our Nation's energy and transportation systems, threatening more frequent and longer-lasting power

outages, fuel shortages, and service disruptions, with cascading impacts on other critical sectors. Infrastructure currently designed for historical climate conditions is more vulnerable to future weather extremes and climate change. The continued increase in the frequency and extent of high-tide flooding due to sea level rise threatens America's trillion-dollar coastal property market and public infrastructure, with cascading impacts to the larger economy. In Alaska, rising temperatures and erosion are causing damage to buildings and coastal infrastructure that will be costly to repair or replace, particularly in rural areas; these impacts are expected to grow without adaptation. Expected increases in the severity and frequency of heavy precipitation events will affect inland infrastructure in every region, including access to roads, the viability of bridges, and the safety of pipelines. Flooding from heavy rainfall, storm surge, and rising high tides is expected to compound existing issues with aging infrastructure in the Northeast. Increased drought risk will threaten oil and gas drilling and refining, as well as electricity generation from power plants that rely on surface water for cooling. Forward-looking infrastructure design, planning, and operational measures and standards can reduce exposure and vulnerability to the impacts of climate change and reduce energy use while providing additional near-term benefits, including reductions in greenhouse gas emissions."

Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). 2018. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* U.S. Global Change Research Program, Washington, DC, p. 4. https://nca2018.globalchange.gov/)

Appendix II

Additional Material for the Record

EXECUTIVE SUMMARY OF A REPORT SUBMITTED BY REPRESENTATIVE CASTEN

II. Executive Summary

The arctic cold front that descended on the Southwest during the first week of February 2011 was unusually severe in terms of temperature, wind, and duration of the event. In many cities in the Southwest, temperatures remained below freezing for four days, and winds gusted in places to 30 mph or more. The geographic area hit was also extensive, complicating efforts to obtain power and natural gas from neighboring regions.

The storm, however, was not without precedent. There were prior severe cold weather events in the Southwest in 1983, 1989, 2003, 2006, 2008, and 2010. The worst of these was in 1989, the prior event most comparable to 2011. That year marked the first time ERCOT resorted to system-wide rolling blackouts to prevent more widespread customer outages. In all of those prior years, the natural gas delivery system experienced production declines; however, curtailments to natural gas customers in the region were essentially limited to the years 1989 and 2003.

Electric

Going into the February 2011 storm, neither ERCOT nor the other electric entities that initiated rolling blackouts during the event expected to have a problem meeting customer demand. They all had adequate reserve margins, based on anticipated generator availability. But those reserves proved insufficient for the extraordinary amount of capacity that was lost during the event from trips, derates, and failures to start.

In the case of ERCOT, where rolling blackouts affected the largest number of customers (3.2 million), there were 3100 MW of responsive reserves available on the first day of the event, compared to a minimum requirement of 2300 MW. But over the course of that day and the next, a total of 193 ERCOT generating units failed or were derated, representing a cumulative loss of 29,729 MW. Combining forced outages with scheduled outages, approximately one-third of the total ERCOT fleet was unavailable at the lowest point of the event. These extensive generator failures overwhelmed ERCOT's reserves, which eventually dropped below the level of safe operation. Had ERCOT not acted promptly to shed load, it would very likely have suffered widespread, uncontrolled blackouts throughout the entire ERCOT Interconnection.

ERCOT also experienced generator outages in the Rio Grande Valley on February 3, again due to the cold weather. This area is transmission constrained, and the loss of local generation led to voltage concerns that necessitated localized load shedding.

Spot prices in ERCOT hit the $3,000 per MWh cap on February 2, the worst day of the event. Given the high demand and the huge loss of generation, this was not a surprising development. In fact, very high prices are an expected response to scarcity conditions, one that is built into ERCOT's energy-only market. ERCOT's IMM reviewed market performance during the event and found no evidence of market manipulation.

EPE and SRP likewise suffered numerous generator outages, necessitating load shed of 1023 MW in EPE's case, and 300 MW in SRP's case. As with ERCOT, many of these generators failed because of weather-related reasons.

A number of entities within SPP also experienced outages during the event. In their case, however, load shedding was not required, principally because the utilities were able to purchase emergency energy from other SPP members. One other utility in the Southwest, PNM, experienced blackouts, but these were localized and the result of transmission outages that were mostly unrelated to the weather.

The actions of the entities in calling for and carrying out the rolling blackouts were largely effective and timely. However, the massive amount of generator failures that were experienced raises the question whether it would have been helpful to increase reserve levels going into the event. This action would have brought more units online earlier, might have prevented some of the freezing problems the generators experienced, and could have exposed operational problems in time to implement corrections before the units were needed to meet customer demand.

The February event underscores the need to have sufficient black start units available, particularly in the face of an anticipated severe weather event. In ERCOT's case, for instance, nearly half of its black start units were either on scheduled outage at the time of the event or failed during the event itself, jeopardizing the utility's ability to promptly restore the system had an uncontrolled, ERCOT-wide blackout occurred.

The majority of the problems experienced by the many generators that tripped, suffered derates, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. For the Southwest as a whole, 67 percent of the generator failures (by MWh) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, low temperature cutoff limits, and the like. At least another 12 percent were indirectly attributable to the weather (occasioned by natural gas curtailments to gas-fired generators and difficulties in fuel switching).

Low temperatures returned to the region on February 10. In fact, ERCOT set a new winter peak that day. But no load shedding proved necessary, largely because the temperatures were not quite as cold or sustained as those of the previous week, the winds were less severe, and many of the repairs and protective measures taken by the generators on February 2 remained in place.

Natural Gas

Problems on the natural gas side largely resulted from production declines in the five basins serving the Southwest. For the period February 1 through February 5, an estimated 14.8 Bcf of production was lost. These declines propagated downstream through the rest of the gas delivery chain, ultimately resulting in natural gas curtailments to more than 50,000 customers in New Mexico, Arizona, and Texas.

The production losses stemmed principally from three things: freeze-offs, icy roads, and rolling electric blackouts or customer curtailments. Freeze-offs occurred when the small amount of water produced alongside the natural gas crystallized or froze, completely blocking off the gas flow and shutting down the well. Freeze-offs routinely occur in very cold weather, and affected at least some of these basins in all of the six recent cold weather events in the Southwest with the possible exception of 1983, for which adequate records are not available. During the February event, icy roads prevented maintenance personnel and equipment from reaching the wells and hauling off produced water which, if left in holding tanks at the wellhead, causes the wells to shut down automatically. The ERCOT blackouts or customer curtailments affected primarily the Permian and Fort Worth Basins and caused or contributed to 29 percent (Permian) and 27 percent (Fort Worth) of the production outages, principally as a result of shutting down electric pumping units or compressors on gathering lines.

Processing plants suffered some mechanical failures, although most of their shortfalls resulted from problems upstream at the wellhead. The production declines, coupled with increased customer demand, reduced gas volume and pressure in the pipelines and in those limited storage facilities serving the Southwest. These entities in turn were unable in some instances to deliver adequate gas supplies to LDCs.

When LDCs suffer declines in gas pressure on their systems, they must reduce the amount of gas being consumed to prevent pressures from falling so low that their entire systems might fail. As a result of the high gas demand and the falling pressures on their systems, four LDCs in New Mexico, Arizona and Texas were forced to curtail retail service or were unable to supply gas to all customers. These curtailments or outages affected more than 50,000 customers in those states, including the cities of El Paso in Texas; Tucson and Sierra Vista in Arizona; and Hobbs, Ruidoso, Alamogordo, Silver City, Tularosa, La Luz, Taos, Red River, Questa, Española, Bernalillo, and Placitas in New Mexico. In contrast to the relative ease of restoring electric service, restoration of gas service was complicated by the necessity to have LDC crews manually shut off gas meters and then relight pilot lights on site.

Winterization

Generators and natural gas producers suffered severe losses of capacity despite having received accurate forecasts of the storm. Entities in both categories report having winterization procedures in place. However, the poor performance of many of these generating units and wells suggests that these procedures were either inadequate or were not adequately followed.

The experiences of 1989 are instructive, particularly on the electric side. In that year, as in 2011, cold weather caused many generators to trip, derate, or fail to start. The PUCT investigated the occurrence and issued a number of recommendations aimed at improving winterization on the part of the generators. These recommendations were not mandatory, and over the course of time implementation lapsed. Many of the generators that experienced outages in 1989 failed again in 2011.

On the gas side, producers experienced production declines in all of the recent prior cold weather events. While these declines rarely led to any significant curtailments, electric generators in 2003 did experience, as a result of gas shortages, widespread derates and in some cases outright unit failure. It is reasonable to assume from this pattern that the level of winterization put in place by producers is not capable of withstanding unusually cold temperatures.

While extreme cold weather events are obviously not as common in the Southwest as elsewhere, they do occur every few years. And when they do, the cost in terms of dollars and human hardship is considerable. The question of what to do about it is not an easy one to answer, as all preventative measures entail some cost. However, in many cases, the needed fixes would not be unduly expensive. Indeed, many utilities have already undertaken improvements in light of their experiences during the February event. This report makes a number of recommendations that the task force believes are both reasonable economically and which would substantially reduce the risk of blackouts and natural gas curtailments during the next extreme cold weather event that hits the Southwest.

FERC/NERC Staff Report on the 2011 Southwest Cold Weather Event

Electric and Gas Interdependency

The report also addresses the interdependency of the electric and natural gas industries. Utilities are becoming increasingly reliant on gas-fired generation, in large part because shale production has dramatically reduced the cost of gas. Likewise, compressors used in the gas industry are more likely than in the past to be powered with electricity, rather than gas. As a result, deficiencies in the supply of either electricity or natural gas affect not only consumers of that commodity, but of the other commodity as well.

Gas shortages were not a significant cause of the electric generator outages experienced during the February 2011 event, nor were rolling blackouts a primary cause of the production declines at the wellhead. Both, however, contributed to the problem, and in the case of natural gas shortfalls in the Permian and Fort Worth Basins, approximately a quarter of the decline was attributed to rolling blackouts or customer curtailments affecting producers.

The report explores some of the issues relating to the effects of shortages of one commodity on the other, including the question of whether gas production and processing facilities should be deemed "human needs" customers and thus exempted or given special consideration for purposes of electric load shedding. However, any resolution of the many issues arising from electric and natural gas interdependency must be informed by an examination of more than one cold weather event in one part of the country. For that reason, the report does not offer specific recommendations in this area, but urges regulatory and industry bodies to explore solutions to the many interdependency problems which are likely to remain of concern in the future.

[For full report see: https://www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf]

DOCUMENTS SUBMITTED BY REPRESENTATIVE POSEY

26595

Federal Register
Vol. 85, No. 86
Monday, May 4, 2020

Presidential Documents

Title 3—

The President

Executive Order 13920 of May 1, 2020

Securing the United States Bulk-Power System

By the authority vested in me as President by the Constitution and the laws of the United States of America, including the International Emergency Economic Powers Act (50 U.S.C. 1701 *et seq.*) (IEEPA), the National Emergencies Act (50 U.S.C. 1601 *et seq.*) (NEA), and section 301 of title 3, United States Code,

I, DONALD J. TRUMP, President of the United States of America, find that foreign adversaries are increasingly creating and exploiting vulnerabilities in the United States bulk-power system, which provides the electricity that supports our national defense, vital emergency services, critical infrastructure, economy, and way of life. The bulk-power system is a target of those seeking to commit malicious acts against the United States and its people, including malicious cyber activities, because a successful attack on our bulk-power system would present significant risks to our economy, human health and safety, and would render the United States less capable of acting in defense of itself and its allies. I further find that the unrestricted acquisition or use in the United States of bulk-power system electric equipment designed, developed, manufactured, or supplied by persons owned by, controlled by, or subject to the jurisdiction or direction of foreign adversaries augments the ability of foreign adversaries to create and exploit vulnerabilities in bulk-power system electric equipment, with potentially catastrophic effects. I therefore determine that the unrestricted foreign supply of bulk-power system electric equipment constitutes an unusual and extraordinary threat to the national security, foreign policy, and economy of the United States, which has its source in whole or in substantial part outside the United States. This threat exists both in the case of individual acquisitions and when acquisitions are considered as a class. Although maintaining an open investment climate in bulk-power system electric equipment, and in the United States economy more generally, is important for the overall growth and prosperity of the United States, such openness must be balanced with the need to protect our Nation against a critical national security threat. To address this threat, additional steps are required to protect the security, integrity, and reliability of bulk-power system electric equipment used in the United States. In light of these findings, I hereby declare a national emergency with respect to the threat to the United States bulk-power system.

Accordingly, I hereby order:

Section 1. *Prohibitions and Implementation.* (a) The following actions are prohibited: any acquisition, importation, transfer, or installation of any bulk-power system electric equipment (transaction) by any person, or with respect to any property, subject to the jurisdiction of the United States, where the transaction involves any property in which any foreign country or a national thereof has any interest (including through an interest in a contract for the provision of the equipment), where the transaction was initiated after the date of this order, and where the Secretary of Energy (Secretary), in coordination with the Director of the Office of Management and Budget and in consultation with the Secretary of Defense, the Secretary of Homeland Security, the Director of National Intelligence, and, as appropriate, the heads of other executive departments and agencies (agencies), has determined that:

(i) the transaction involves bulk-power system electric equipment designed, developed, manufactured, or supplied, by persons owned by, controlled by, or subject to the jurisdiction or direction of a foreign adversary; and

(ii) the transaction:

(A) poses an undue risk of sabotage to or subversion of the design, integrity, manufacturing, production, distribution, installation, operation, or maintenance of the bulk-power system in the United States;

(B) poses an undue risk of catastrophic effects on the security or resiliency of United States critical infrastructure or the economy of the United States; or

(C) otherwise poses an unacceptable risk to the national security of the United States or the security and safety of United States persons.

(b) The Secretary, in consultation with the heads of other agencies as appropriate, may at the Secretary's discretion design or negotiate measures to mitigate concerns identified under section 1(a) of this order. Such measures may serve as a precondition to the approval by the Secretary of a transaction or of a class of transactions that would otherwise be prohibited pursuant to this order.

(c) The prohibitions in subsection (a) of this section apply except to the extent provided by statutes, or in regulations, orders, directives, or licenses that may be issued pursuant to this order, and notwithstanding any contract entered into or any license or permit granted prior to the date of this order.

(d) The Secretary, in consultation with the heads of other agencies as appropriate, may establish and publish criteria for recognizing particular equipment and particular vendors in the bulk-power system electric equipment market as pre-qualified for future transactions; and may apply these criteria to establish and publish a list of pre-qualified equipment and vendors. Nothing in this provision limits the Secretary's authority under this section to prohibit or otherwise regulate any transaction involving pre-qualified equipment or vendors.

Sec. 2. *Authorities.* (a) The Secretary is hereby authorized to take such actions, including directing the timing and manner of the cessation of pending and future transactions prohibited pursuant to section 1 of this order, adopting appropriate rules and regulations, and employing all other powers granted to the President by IEEPA as may be necessary to implement this order. The heads of all agencies, including the Board of Directors of the Tennessee Valley Authority, shall take all appropriate measures within their authority as appropriate and consistent with applicable law, to implement this order.

(b) Rules and regulations issued pursuant to this order may, among other things, determine that particular countries or persons are foreign adversaries exclusively for the purposes of this order; identify persons owned by, controlled by, or subject to the jurisdiction or direction of foreign adversaries exclusively for the purposes of this order; identify particular equipment or countries with respect to which transactions involving bulk-power system electric equipment warrant particular scrutiny under the provisions of this order; establish procedures to license transactions otherwise prohibited pursuant to this order; and identify a mechanism and relevant factors for the negotiation of agreements to mitigate concerns raised in connection with subsection 1(a) of this order. Within 150 days of the date of this order, the Secretary, in consultation with the Secretary of Defense, the Secretary of Homeland Security, the Director of National Intelligence, and, as appropriate, the heads of other agencies, shall publish rules or regulations implementing the authorities delegated to the Secretary by this order.

(c) The Secretary may, consistent with applicable law, redelegate any of the authorities conferred on the Secretary pursuant to this section within the Department of Energy.

(d) As soon as practicable, the Secretary, in consultation with the Secretary of Defense, the Secretary of the Interior, the Secretary of Homeland Security, the Director of National Intelligence, the Board of Directors of the Tennessee Valley Authority, and the heads of such other agencies as the Secretary considers appropriate, shall:

(i) identify bulk-power system electric equipment designed, developed, manufactured, or supplied, by persons owned by, controlled by, or subject to the jurisdiction or direction of a foreign adversary that poses an undue risk of sabotage to or subversion of the design, integrity, manufacturing, production, distribution, installation, operation, or maintenance of the bulk-power system in the United States, poses an undue risk of catastrophic effects on the security or resiliency of United States critical infrastructure or the economy of the United States, or otherwise poses an unacceptable risk to the national security of the United States or the security and safety of United States persons; and

(ii) develop recommendations on ways to identify, isolate, monitor, or replace such items as soon as practicable, taking into consideration overall risk to the bulk-power system.

Sec. 3. *Task Force on Federal Energy Infrastructure Procurement Policies Related to National Security.* (a) There is hereby established a Task Force on Federal Energy Infrastructure Procurement Policies Related to National Security (Task Force), which shall work to protect the Nation from national security threats through the coordination of Federal Government procurement of energy infrastructure and the sharing of risk information and risk management practices to inform such procurement. The Task Force shall be chaired by the Secretary or the Secretary's designee.

(b) In addition to the Chair of the Task Force (Chair), the Task Force membership shall include the following heads of agencies, or their designees:

(i) the Secretary of Defense;

(ii) the Secretary of the Interior;

(iii) the Secretary of Commerce;

(iv) the Secretary of Homeland Security;

(v) the Director of National Intelligence;

(vi) the Director of the Office of Management and Budget; and

(vii) the head of any other agency that the Chair may designate in consultation with the Secretary of Defense and the Secretary of the Interior.

(c) The Task Force shall:

(i) develop a recommended consistent set of energy infrastructure procurement policies and procedures for agencies, to the extent consistent with law, to ensure that national security considerations are fully integrated across the Federal Government, and submit such recommendations to the Federal Acquisition Regulatory Council (FAR Council);

(ii) evaluate the methods and criteria used to incorporate national security considerations into energy security and cybersecurity policymaking;

(iii) consult with the Electricity Subsector Coordinating Council and the Oil and Natural Gas Subsector Coordinating Council in developing the recommendations and evaluation described in subsections (c)(i) through (ii) of this section; and

(iv) conduct any other studies, develop any other recommendations, and submit any such studies and recommendations to the President, as appropriate and as directed by the Secretary.

(d) The Department of Energy shall provide administrative support and funding for the Task Force, to the extent consistent with applicable law.

(e) The Task Force shall meet as required by the Chair and, unless extended by the Chair, shall terminate once it has accomplished the objectives set forth in subsection (c) of this section, as determined by the Chair, and completed the reports described in subsection (f) of this section.

(f) The Task Force shall submit to the President, through the Chair and the Director of the Office of Management and Budget:

(i) a report within 1 year from the date of this order;

(ii) a subsequent report at least once annually thereafter while the Task Force remains in existence; and

(iii) such other reports as appropriate and as directed by the Chair.

(g) In the reports submitted under subsection (f) of this section, the Task Force shall summarize its progress, findings, and recommendations described in subsection (c) of this section.

(h) Because attacks on the bulk-power system can originate through the distribution system, the Task Force shall engage with distribution system industry groups, to the extent consistent with law and national security. Within 180 days of receiving the recommendations pursuant to subsection (c)(i) of this section, the FAR Council shall consider proposing for notice and public comment an amendment to the applicable provisions in the Federal Acquisition Regulation to implement the recommendations provided pursuant to subsection (c)(i) of this section.

Sec. 4. *Definitions.* For purposes of this order, the following definitions shall apply:

(a) The term "bulk-power system" means (i) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and (ii) electric energy from generation facilities needed to maintain transmission reliability. For the purpose of this order, this definition includes transmission lines rated at 69,000 volts (69 kV) or more, but does not include facilities used in the local distribution of electric energy.

(b) The term "bulk-power system electric equipment" means items used in bulk-power system substations, control rooms, or power generating stations, including reactors, capacitors, substation transformers, current coupling capacitors, large generators, backup generators, substation voltage regulators, shunt capacitor equipment, automatic circuit reclosers, instrument transformers, coupling capacity voltage transformers, protective relaying, metering equipment, high voltage circuit breakers, generation turbines, industrial control systems, distributed control systems, and safety instrumented systems. Items not included in the preceding list and that have broader application of use beyond the bulk-power system are outside the scope of this order.

(c) The term "entity" means a partnership, association, trust, joint venture, corporation, group, subgroup, or other organization.

(d) The term "foreign adversary" means any foreign government or foreign non-government person engaged in a long-term pattern or serious instances of conduct significantly adverse to the national security of the United States or its allies or the security and safety of United States persons.

(e) The term "person" means an individual or entity.

(f) The term "procurement" means the acquiring by contract with appropriated funds of supplies or services, including installation services, by and for the use of the Federal Government, through purchase, whether the supplies or services are already in existence or must be created, developed, demonstrated, and evaluated.

(g) The term "United States person" means any United States citizen, permanent resident alien, entity organized under the laws of the United States or any jurisdiction within the United States (including foreign branches), or any person in the United States.

Sec. 5. *Recurring and Final Reports to the Congress.* The Secretary is hereby authorized to submit recurring and final reports to the Congress regarding the national emergency declared in this order, consistent with section 401(c) of the NEA (50 U.S.C. 1641(c)) and section 204(c) of IEEPA (50 U.S.C. 1703(c)).

Sec. 6. *General Provisions.* (a) Nothing in this order shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(b) This order shall be implemented consistent with applicable law and subject to the availability of appropriations.

(c) This order is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.

THE WHITE HOUSE,
May 1, 2020.

[FR Doc. 2020–09695
Filed 5–1–20; 2:30 pm]
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Presidential Documents

Executive Order 13990 of January 20, 2021

Protecting Public Health and the Environment and Restoring Science To Tackle the Climate Crisis

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. *Policy.* Our Nation has an abiding commitment to empower our workers and communities; promote and protect our public health and the environment; and conserve our national treasures and monuments, places that secure our national memory. Where the Federal Government has failed to meet that commitment in the past, it must advance environmental justice. In carrying out this charge, the Federal Government must be guided by the best science and be protected by processes that ensure the integrity of Federal decision-making. It is, therefore, the policy of my Administration to listen to the science; to improve public health and protect our environment; to ensure access to clean air and water; to limit exposure to dangerous chemicals and pesticides; to hold polluters accountable, including those who disproportionately harm communities of color and low-income communities; to reduce greenhouse gas emissions; to bolster resilience to the impacts of climate change; to restore and expand our national treasures and monuments; and to prioritize both environmental justice and the creation of the well-paying union jobs necessary to deliver on these goals.

To that end, this order directs all executive departments and agencies (agencies) to immediately review and, as appropriate and consistent with applicable law, take action to address the promulgation of Federal regulations and other actions during the last 4 years that conflict with these important national objectives, and to immediately commence work to confront the climate crisis.

Sec. 2. *Immediate Review of Agency Actions Taken Between January 20, 2017, and January 20, 2021.* (a) The heads of all agencies shall immediately review all existing regulations, orders, guidance documents, policies, and any other similar agency actions (agency actions) promulgated, issued, or adopted between January 20, 2017, and January 20, 2021, that are or may be inconsistent with, or present obstacles to, the policy set forth in section 1 of this order. For any such actions identified by the agencies, the heads of agencies shall, as appropriate and consistent with applicable law, consider suspending, revising, or rescinding the agency actions. In addition, for the agency actions in the 4 categories set forth in subsections (i) through (iv) of this section, the head of the relevant agency, as appropriate and consistent with applicable law, shall consider publishing for notice and comment a proposed rule suspending, revising, or rescinding the agency action within the time frame specified.

(i) Reducing Methane Emissions in the Oil and Gas Sector: "Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources Reconsideration," 85 FR 57398 (September 15, 2020), by September 2021.

(ii) Establishing Ambitious, Job-Creating Fuel Economy Standards: "The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule Part One: One National Program," 84 FR 51310 (September 27, 2019), by April 2021; and "The Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021–2026 Passenger Cars and Light Trucks," 85 FR 24174 (April 30, 2020), by July 2021. In considering whether to propose suspending, revising, or rescinding the latter rule, the agency should consider the views of representatives from labor unions, States, and industry.

(iii) Job-Creating Appliance- and Building-Efficiency Standards: "Energy Conservation Program for Appliance Standards: Procedures for Use in New or Revised Energy Conservation Standards and Test Procedures for Consumer Products and Commercial/Industrial Equipment," 85 FR 8626 (February 14, 2020), with major revisions proposed by March 2021 and any remaining revisions proposed by June 2021; "Energy Conservation Program for Appliance Standards: Procedures for Evaluating Statutory Factors for Use in New or Revised Energy Conservation Standards," 85 FR 50937 (August 19, 2020), with major revisions proposed by March 2021 and any remaining revisions proposed by June 2021; "Final Determination Regarding Energy Efficiency Improvements in the 2018 International Energy Conservation Code (IECC)," 84 FR 67435 (December 10, 2019), by May 2021; "Final Determination Regarding Energy Efficiency Improvements in ANSI/ASHRAE/IES Standard 90.1–2016: Energy Standard for Buildings, Except Low-Rise Residential Buildings," 83 FR 8463 (February 27, 2018), by May 2021.

(iv) Protecting Our Air from Harmful Pollution: "National Emission Standards for Hazardous Air Pollutants: Coal- and Oil-Fired Electric Utility Steam Generating Units—Reconsideration of Supplemental Finding and Residual Risk and Technology Review," 85 FR 31286 (May 22, 2020), by August 2021; "Increasing Consistency and Transparency in Considering Benefits and Costs in the Clean Air Act Rulemaking Process," 85 FR 84130 (December 23, 2020), as soon as possible; "Strengthening Transparency in Pivotal Science Underlying Significant Regulatory Actions and Influential Scientific Information," 86 FR 469 (January 6, 2021), as soon as possible.

(b) Within 30 days of the date of this order, heads of agencies shall submit to the Director of the Office of Management and Budget (OMB) a preliminary list of any actions being considered pursuant to section (2)(a) of this order that would be completed by December 31, 2021, and that would be subject to OMB review. Within 90 days of the date of this order, heads of agencies shall submit to the Director of OMB an updated list of any actions being considered pursuant to section (2)(a) of this order that would be completed by December 31, 2025, and that would be subject to OMB review. At the time of submission to the Director of OMB, heads of agencies shall also send each list to the National Climate Advisor. In addition, and at the same time, heads of agencies shall send to the National Climate Advisor a list of additional actions being considered pursuant to section (2)(a) of this order that would not be subject to OMB review.

(c) Heads of agencies shall, as appropriate and consistent with applicable law, consider whether to take any additional agency actions to fully enforce the policy set forth in section 1 of this order. With respect to the Administrator of the Environmental Protection Agency, the following specific actions should be considered:

(i) proposing new regulations to establish comprehensive standards of performance and emission guidelines for methane and volatile organic compound emissions from existing operations in the oil and gas sector, including the exploration and production, transmission, processing, and storage segments, by September 2021; and

(ii) proposing a Federal Implementation Plan in accordance with the Environmental Protection Agency's "Findings of Failure To Submit State Implementation Plan Revisions in Response to the 2016 Oil and Natural Gas Industry Control Techniques Guidelines for the 2008 Ozone National Ambient Air Quality Standards (NAAQS) and for States in the Ozone Transport Region," 85 FR 72963 (November 16, 2020), for California, Connecticut, New York, Pennsylvania, and Texas by January 2022.

(d) The Attorney General may, as appropriate and consistent with applicable law, provide notice of this order and any actions taken pursuant to section 2(a) of this order to any court with jurisdiction over pending litigation related to those agency actions identified pursuant to section (2)(a) of this order, and may, in his discretion, request that the court stay or otherwise dispose of litigation, or seek other appropriate relief consistent with this order, until the completion of the processes described in this order.

(e) In carrying out the actions directed in this section, heads of agencies shall seek input from the public and stakeholders, including State local, Tribal, and territorial officials, scientists, labor unions, environmental advocates, and environmental justice organizations.

Sec. 3. *Restoring National Monuments.* (a) The Secretary of the Interior, as appropriate and consistent with applicable law, including the Antiquities Act, 54 U.S.C. 320301 *et seq.*, shall, in consultation with the Attorney General, the Secretaries of Agriculture and Commerce, the Chair of the Council on Environmental Quality, and Tribal governments, conduct a review of the monument boundaries and conditions that were established by Proclamation 9681 of December 4, 2017 (Modifying the Bears Ears National Monument); Proclamation 9682 of December 4, 2017 (Modifying the Grand Staircase-Escalante National Monument); and Proclamation 10049 of June 5, 2020 (Modifying the Northeast Canyons and Seamounts Marine National Monument), to determine whether restoration of the monument boundaries and conditions that existed as of January 20, 2017, would be appropriate.

(b) Within 60 days of the date of this order, the Secretary of the Interior shall submit a report to the President summarizing the findings of the review conducted pursuant to subsection (a), which shall include recommendations for such Presidential actions or other actions consistent with law as the Secretary may consider appropriate to carry out the policy set forth in section 1 of this order.

(c) The Attorney General may, as appropriate and consistent with applicable law, provide notice of this order to any court with jurisdiction over pending litigation related to the Grand Staircase-Escalante, Bears Ears, and Northeast Canyons and Seamounts Marine National Monuments, and may, in his discretion, request that the court stay the litigation or otherwise delay further litigation, or seek other appropriate relief consistent with this order, pending the completion of the actions described in subsection (a) of this section.

Sec. 4. *Arctic Refuge.* (a) In light of the alleged legal deficiencies underlying the program, including the inadequacy of the environmental review required by the National Environmental Policy Act, the Secretary of the Interior shall, as appropriate and consistent with applicable law, place a temporary moratorium on all activities of the Federal Government relating to the implementation of the Coastal Plain Oil and Gas Leasing Program, as established by the Record of Decision signed August 17, 2020, in the Arctic National Wildlife Refuge. The Secretary shall review the program and, as appropriate and consistent with applicable law, conduct a new, comprehensive analysis of the potential environmental impacts of the oil and gas program.

(b) In Executive Order 13754 of December 9, 2016 (Northern Bering Sea Climate Resilience), and in the Presidential Memorandum of December 20, 2016 (Withdrawal of Certain Portions of the United States Arctic Outer Continental Shelf From Mineral Leasing), President Obama withdrew areas in Arctic waters and the Bering Sea from oil and gas drilling and established the Northern Bering Sea Climate Resilience Area. Subsequently, the order was revoked and the memorandum was amended in Executive Order 13795 of April 28, 2017 (Implementing an America-First Offshore Energy Strategy). Pursuant to section 12(a) of the Outer Continental Shelf Lands Act, 43 U.S.C. 1341(a), Executive Order 13754 and the Presidential Memorandum of December 20, 2016, are hereby reinstated in their original form, thereby restoring the original withdrawal of certain offshore areas in Arctic waters and the Bering Sea from oil and gas drilling.

(c) The Attorney General may, as appropriate and consistent with applicable law, provide notice of this order to any court with jurisdiction over pending litigation related to the Coastal Plain Oil and Gas Leasing Program in the Arctic National Wildlife Refuge and other related programs, and may, in his discretion, request that the court stay the litigation or otherwise delay further litigation, or seek other appropriate relief consistent with this order, pending the completion of the actions described in subsection (a) of this section.

Sec. 5. *Accounting for the Benefits of Reducing Climate Pollution.* (a) It is essential that agencies capture the full costs of greenhouse gas emissions as accurately as possible, including by taking global damages into account. Doing so facilitates sound decision-making, recognizes the breadth of climate impacts, and supports the international leadership of the United States on climate issues. The "social cost of carbon" (SCC), "social cost of nitrous oxide" (SCN), and "social cost of methane" (SCM) are estimates of the monetized damages associated with incremental increases in greenhouse gas emissions. They are intended to include changes in net agricultural productivity, human health, property damage from increased flood risk, and the value of ecosystem services. An accurate social cost is essential for agencies to accurately determine the social benefits of reducing greenhouse gas emissions when conducting cost-benefit analyses of regulatory and other actions.

(b) There is hereby established an Interagency Working Group on the Social Cost of Greenhouse Gases (the "Working Group"). The Chair of the Council of Economic Advisers, Director of OMB, and Director of the Office of Science and Technology Policy shall serve as Co-Chairs of the Working Group.

(i) Membership. The Working Group shall also include the following other officers, or their designees: the Secretary of the Treasury; the Secretary of the Interior; the Secretary of Agriculture; the Secretary of Commerce; the Secretary of Health and Human Services; the Secretary of Transportation; the Secretary of Energy; the Chair of the Council on Environmental Quality; the Administrator of the Environmental Protection Agency; the Assistant to the President and National Climate Advisor; and the Assistant to the President for Economic Policy and Director of the National Economic Council.

(ii) Mission and Work. The Working Group shall, as appropriate and consistent with applicable law:

(A) publish an interim SCC, SCN, and SCM within 30 days of the date of this order, which agencies shall use when monetizing the value of changes in greenhouse gas emissions resulting from regulations and other relevant agency actions until final values are published;

(B) publish a final SCC, SCN, and SCM by no later than January 2022;

(C) provide recommendations to the President, by no later than September 1, 2021, regarding areas of decision-making, budgeting, and procurement by the Federal Government where the SCC, SCN, and SCM should be applied;

(D) provide recommendations, by no later than June 1, 2022, regarding a process for reviewing, and, as appropriate, updating, the SCC, SCN, and SCM to ensure that these costs are based on the best available economics and science; and

(E) provide recommendations, to be published with the final SCC, SCN, and SCM under subparagraph (A) if feasible, and in any event by no later than June 1, 2022, to revise methodologies for calculating the SCC, SCN, and SCM, to the extent that current methodologies do not adequately take account of climate risk, environmental justice, and intergenerational equity.

(iii) Methodology. In carrying out its activities, the Working Group shall consider the recommendations of the National Academies of Science, Engineering, and Medicine as reported in Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide (2017) and other pertinent scientific literature; solicit public comment; engage with the public and stakeholders; seek the advice of ethics experts; and ensure that the SCC, SCN, and SCM reflect the interests of future generations in avoiding threats posed by climate change.

Sec. 6. *Revoking the March 2019 Permit for the Keystone XL Pipeline.* (a) On March 29, 2019, the President granted to TransCanada Keystone Pipeline, L.P. a Presidential permit (the "Permit") to construct, connect, operate, and maintain pipeline facilities at the international border of the United States and Canada (the "Keystone XL pipeline"), subject to express conditions and potential revocation in the President's sole discretion. The Permit is hereby revoked in accordance with Article 1(1) of the Permit.

(b) In 2015, following an exhaustive review, the Department of State and the President determined that approving the proposed Keystone XL pipeline would not serve the U.S. national interest. That analysis, in addition to concluding that the significance of the proposed pipeline for our energy security and economy is limited, stressed that the United States must prioritize the development of a clean energy economy, which will in turn create good jobs. The analysis further concluded that approval of the proposed pipeline would undermine U.S. climate leadership by undercutting the credibility and influence of the United States in urging other countries to take ambitious climate action.

(c) Climate change has had a growing effect on the U.S. economy, with climate-related costs increasing over the last 4 years. Extreme weather events and other climate-related effects have harmed the health, safety, and security of the American people and have increased the urgency for combatting climate change and accelerating the transition toward a clean energy economy. The world must be put on a sustainable climate pathway to protect Americans and the domestic economy from harmful climate impacts, and to create well-paying union jobs as part of the climate solution.

(d) The Keystone XL pipeline disserves the U.S. national interest. The United States and the world face a climate crisis. That crisis must be met with action on a scale and at a speed commensurate with the need to avoid setting the world on a dangerous, potentially catastrophic, climate trajectory. At home, we will combat the crisis with an ambitious plan to build back better, designed to both reduce harmful emissions and create good clean-energy jobs. Our domestic efforts must go hand in hand with U.S. diplomatic engagement. Because most greenhouse gas emissions originate beyond our borders, such engagement is more necessary and urgent than ever. The United States must be in a position to exercise vigorous climate leadership in order to achieve a significant increase in global climate action and put the world on a sustainable climate pathway. Leaving the Keystone XL pipeline permit in place would not be consistent with my Administration's economic and climate imperatives.

Sec. 7. *Other Revocations.* (a) Executive Order 13766 of January 24, 2017 (Expediting Environmental Reviews and Approvals For High Priority Infrastructure Projects), Executive Order 13778 of February 28, 2017 (Restoring the Rule of Law, Federalism, and Economic Growth by Reviewing the "Waters of the United States" Rule), Executive Order 13783 of March 28, 2017 (Promoting Energy Independence and Economic Growth), Executive Order 13792 of April 26, 2017 (Review of Designations Under the Antiquities Act), Executive Order 13795 of April 28, 2017 (Implementing an America-First Offshore Energy Strategy), Executive Order 13868 of April 10, 2019 (Promoting Energy Infrastructure and Economic Growth), and Executive Order 13927 of June 4, 2020 (Accelerating the Nation's Economic Recovery from the COVID–19 Emergency by Expediting Infrastructure Investments and Other Activities), are hereby revoked. Executive Order 13834 of May 17, 2018

(Efficient Federal Operations), is hereby revoked except for sections 6, 7, and 11.

(b) Executive Order 13807 of August 15, 2017 (Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure Projects), is hereby revoked. The Director of OMB and the Chair of the Council on Environmental Quality shall jointly consider whether to recommend that a replacement order be issued.

(c) Executive Order 13920 of May 1, 2020 (Securing the United States Bulk-Power System), is hereby suspended for 90 days. The Secretary of Energy and the Director of OMB shall jointly consider whether to recommend that a replacement order be issued.

(d) The Presidential Memorandum of April 12, 2018 (Promoting Domestic Manufacturing and Job Creation Policies and Procedures Relating to Implementation of Air Quality Standards), the Presidential Memorandum of October 19, 2018 (Promoting the Reliable Supply and Delivery of Water in the West), and the Presidential Memorandum of February 19, 2020 (Developing and Delivering More Water Supplies in California), are hereby revoked.

(e) The Council on Environmental Quality shall rescind its draft guidance entitled, "Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions," 84 FR 30097 (June 26, 2019). The Council, as appropriate and consistent with applicable law, shall review, revise, and update its final guidance entitled, "Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews," 81 FR 51866 (August 5, 2016).

(f) The Director of OMB and the heads of agencies shall promptly take steps to rescind any orders, rules, regulations, guidelines, or policies, or portions thereof, including, if necessary, by proposing such rescissions through notice-and-comment rulemaking, implementing or enforcing the Executive Orders, Presidential Memoranda, and draft guidance identified in this section, as appropriate and consistent with applicable law.

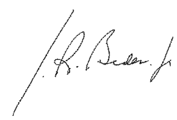
Sec. 8. *General Provisions.* (a) Nothing in this order shall be construed to impair or otherwise affect:

(i) the authority granted by law to an executive department or agency, or the head thereof; or

(ii) the functions of the Director of the Office of Management and Budget relating to budgetary, administrative, or legislative proposals.

(b) This order shall be implemented in a manner consistent with applicable law and subject to the availability of appropriations.

(c) This order is not intended to, and does not, create any right or benefit, substantive or procedural, enforceable at law or in equity by any party against the United States, its departments, agencies, or entities, its officers, employees, or agents, or any other person.



THE WHITE HOUSE,
January 20, 2021.

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ARTICLE SUBMITTED BY REPRESENTATIVE POSEY

WASHINGTON TIMES: Lessons of the China-India Blackout War

Protecting the Power Grid Illustration by Greg Groesch/The Washington Times more >

By Dr. Peter Vincent Pry - - *Tuesday, March 16, 2021*
ANALYSIS/OPINION:

The future usually arrives before anyone is ready for it, especially in warfare.

China apparently blacked-out Mumbai, India, by cyber-attack — credibly threatening that Beijing could plunge all India into darkness through cyber warfare. Experts warn national electric grids are a technological Achilles heel.

The Mumbai blackout could be one of those "Monitor versus Merrimack" moments in military history when a revolutionary new way of warfare suddenly becomes recognizable, even to the dullest.

New military technologies that can change everything are often laughingly dismissed by establishments too busy planning for "business as usual."

From machine guns at the Somme (1916), panzer divisions in France (1940) and (Japanese) carrier aviation at Pearl Harbor (1941), nations learned the hard way. Obsolete thinking prevails until someone gets hammered, usually by an aggressor.

The Mumbai cyber-blackout, like Russia's annual cyber-blackouts of Ukraine, and blackouts in Mexico (2013), Yemen (2014) and Pakistan (2015) caused by terrorist sabotage of electric grids, are a new category of warfare.

These "blackout wars" foreshadow an existential threat that could end our civilization and kill millions of Americans.

Why did Beijing blackout Mumbai?

China and India are fighting over borders in the Himalayas, again. Ever since China swallowed Tibet in 1951, Beijing periodically tries expanding at India's expense.

But today China and India are both nuclear-armed, so fighting is deliberately "restrained" to avoid nuclear escalation.

Both refrain from a "shooting war" with modern weapons for control of the high Himalayas. Instead, their combat uses shovels, clubs and fists, the two nuclear powers fighting, on top of the world, with stone age tactics.

China evidently thinks threatening cyber-blackout of India could settle matters, without escalation to conventional or nuclear conflict. Protracted blackout of India's electric grid would be catastrophic for its economy, population and military capabilities.

Indian officials are understandably alarmed and now regretting that their national electric power grid and other critical infrastructures depend so much upon equipment imported from China — that likely increases their vulnerability.

"Military experts in India have renewed calls for the government of Prime Minister Narendra Modi to replace China-made hardware for India's power sector and its critical rail system," reports The New York Times in "China Appears To Warn India: Push Too Hard And The Lights Could Go Out" (Feb. 28, 2021).

The New York Times describes technical details of China's blackout war against India. But conspicuous by its absence is any mention of President Biden's suspension of President Trump's Executive Order 13920, "Securing the United States Bulk-Power System" (May 1, 2020), designed to reduce dependency on foreign-supplied equipment for the U.S. electric power grid, especially equipment from China.

Reportedly there are some 300 high-voltage transformers in the U.S. electric power grid manufactured in China. Moreover, the U.S. national grid depends upon an as yet unknown number of China-supplied control systems, called SCADAs, probably numbering in the thousands.

These China-supplied systems, critically important to the operation of the U.S. electric grid, could have built-in vulnerabilities to cyber-bugs and electromagnetic pulse (EMP). China's version of cyber warfare includes attack by nuclear and non-nuclear EMP weapons (See my report "China: EMP Threat" June 10, 2020).

Mr. Biden would be wise to strengthen and reinstate Executive Order 13920. Electricity is foundational to U.S. national security.

Critical equipment necessary to the operation of the national power grid — that sustains the economy, military, and population — should be made in America.

The Biden administration deserves great credit for continuing implementation of the White House "Executive Order on Coordinating National Resilience to Electromagnetic Pulses" (March 26, 2019), designed to implement recommendations of the Congressional EMP Commission. One strategy for achieving resilience of electric grids and other critical infrastructures is to require through national manufacturing standards that transformers, SCADAs, and other vital equipment incorporate EMP and cyber-protection.

Most electric equipment is already manufactured resistant to lightning, a form of natural EMP. Standards could be upgraded to protect against "super-lightning" from EMP weapons.

Defense Department experience over 50 years manufacturing military equipment with nuclear EMP protection "baked-in" the original design increases costs only 1% to 6%.

Mr. Biden and the new White House "cyber-security czar" should compel electric utilities to protect themselves from cyber-attack and EMP. Hundreds are dead from California wildfires and a Texas ice storm because FERC and NERC failed to make utilities undertake simple preparedness for severe weather. They cannot be trusted to protect against cyber-attacks and EMP.

Utility lobbyists advocate retaliatory cyber-attacks by the U.S. government for "deterrence" instead of protecting electric grids.

Retaliatory cyber warfare cannot substitute for hardening critical infrastructures against cyber-attack and EMP — and is very risky. The U.S. is far more vulnerable than its adversaries. Russia and China make frequent cyber-attacks on the U.S. because they know we are vulnerable, and know they can hit back harder.

Moreover, Beijing apparently thinks blacking out India's national electric grid is less escalatory than a "shooting war" in the Himalayas. In 2020, China's strategists threatened EMP attack on the U.S. Navy in the South China Sea, as one of their "less escalatory" options.

Cyber warfare between nuclear-armed powers is not a good idea, for either side. 2021 could too easily become a nuclear version of 1914.

•Dr. Peter Vincent Pry, director of the Task Force on National and Homeland Security, served as chief of staff on the Congressional EMP Commission, and on the staffs of the House Armed

Service Committee and the CIA. He is author most recently of "The Power And The Light" (Amazon.com).

https://www.washingtontimes.com/news/2021/mar/16/lessons-of-the-china-india-blackout-war/

REPORT SUBMITTED BY REPRESENTATIVE BABIN

AMERICAN EXPLORATION & PRODUCTION COUNCIL

Bottom Line - Natural gas is a critical part of a reliable and resilient energy grid

- **Natural gas carried most of the energy load in Texas, and without its contributions the energy picture would have been far worse.**
- Additional improvements in infrastructure and processes would help make natural gas systems even more resilient.
- As in California last summer, events in Texas underscore the need for a diverse energy supply and smart planning to support the health of the U.S. power grid.
- Natural gas, unique among energy sources in it's ability to scale up quickly is critical to ensure grid reliability during extreme weather events or in peak demand.
- Gas responded to high demands and gas production outages by withdrawing gas from storage.
- Widespread freezing rain reduced the operability of many wind turbines and overcast conditions limited solar output. **Natural gas generation quickly surged to fill the void, then continued increasing to meet the dramatic increase in demand while coal and nuclear held constant.**